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The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association

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The Journal of Bone and Joint Surgery

American Volume

EDITORIAL

With this issue, *The Journal* appears under a new plan of co-publication by the American and British Orthopaedic Associations. It will be published in two volumes. There will be eight issues; four will be edited and published in Great Britain (the British Volume) and four in the United States of America (the American Volume). American and British issues will appear alternately at six-week intervals.

The British Volume will be representative of orthopaedic surgery in the British Commonwealth of Nations; the American Volume, of the United States of America. From all nations, articles contributing to the development of the specialty will be welcome.

The trend of policy that has led to the present plan is suggested by a glance into the past. *The Journal* originated in 1889 as the *Transactions of The American Orthopaedic Association*. In 1903, it became national in scope and was called *The American Journal of Orthopaedic Surgery*. During the war years, 1914 to 1918, the accomplishment of many British and American surgeons, working together under the guidance of Sir Robert Jones, had been outstanding. Joint publication of *The Journal* offered a means of continuing the cooperation. In 1919, *The American Journal of Orthopaedic Surgery* became the official organ of The British Orthopaedic Association. Greater benefit to the orthopaedic surgery of each country was anticipated from the interchange of ideas through a common publication. To signalize the broader aim, the name became *The Journal of Orthopaedic Surgery*. Later, the name was changed to *The Journal of Bone and Joint Surgery*.

Thirty years ago, the growth of medicine had become rapid. With expansion came the development of all branches of medicine and surgery. In 1922, orthopaedic surgery was becoming established as a specialty. At that time The American Orthopaedic Association extended the scope of *The Journal* by including articles representative of diverse viewpoints throughout the world. That year, Dr. E. G. Brackett became the Editor of *The Journal*. During the twenty years of his editorship, Dr. Brackett built *The Journal* that we know today. Always the development of its international character was uppermost in his mind. The surgery of any land may reach its highest attainment through the free interchange of ideas from widely scattered sources; surgery, like pure science, belongs to the world.

The Journal has grown as the need for ampler expression has increased. The importance of further expansion has become evident. In many countries, orthopaedic surgery has reached a high degree of development. Freer expression of national trends has become necessary. Increased space has been needed for articles from all countries. Orthopaedic surgeons in Great Britain and in America have had to decide whether the best interests of the surgery of their countries lay in separate or in cooperative publication.

In the spring of 1947, representatives of The American Orthopaedic Association, The British Orthopaedic Association, and The American Academy of Orthopaedic Surgeons met in London to formulate plans to continue the long association and at the same time more fully meet the growing needs of the specialty. From their recommendations came the new plan of publication under which *The Journal* now appears.

With belief in the wisdom of the new plan and confident of the support of surgeons everywhere, the Editorial Boards will endeavor to uphold the standards of *The Journal* and to maintain its aim,—the advancement of orthopaedic surgery.

William A. Rogers

THE MECHANISM AND TREATMENT OF FRACTURES OF THE CALCANEUS

Open Reduction with the Use of Cancellous Grafts

BY IVAR PALMER, M.D., STOCKHOLM, SWEDEN

From Södersjukhuset, Stockholm

Many details of the mechanism and pathological anatomy of fractures of the calcaneus are unknown. The complex structure and anatomical relationships of the calcaneus have made it difficult to clarify the exact nature of these fractures. The roentgenograms are not easily interpreted and often tell only part of the truth. Certain aspects of these fractures are better understood, however, when observed against a background of experience gained by surgical exposure of the fragments.

MECHANISM OF INJURY

The usual explanation of the mechanism of fractures of the calcaneus is that a fall from a height causes the talus, which constitutes the wedgelike pinnacle of the longitudinal arch, to be driven down upon and to break the calcaneus, which forms the large posterior foundation of the arch. This sketchy explanation may be correct in certain fractures of the calcaneus; it throws little light, however, upon the exact nature of the injury. The problem may be simplified by regarding each fracture of the calcaneus as a linear fracture of one of three types,—avulsion, compression, or shearing. Shearing fractures are caused by the simultaneous action of two adjacent, but opposed, parallel forces. In a fall, the part of the tuber calcanei which first strikes the ground is forced upward by

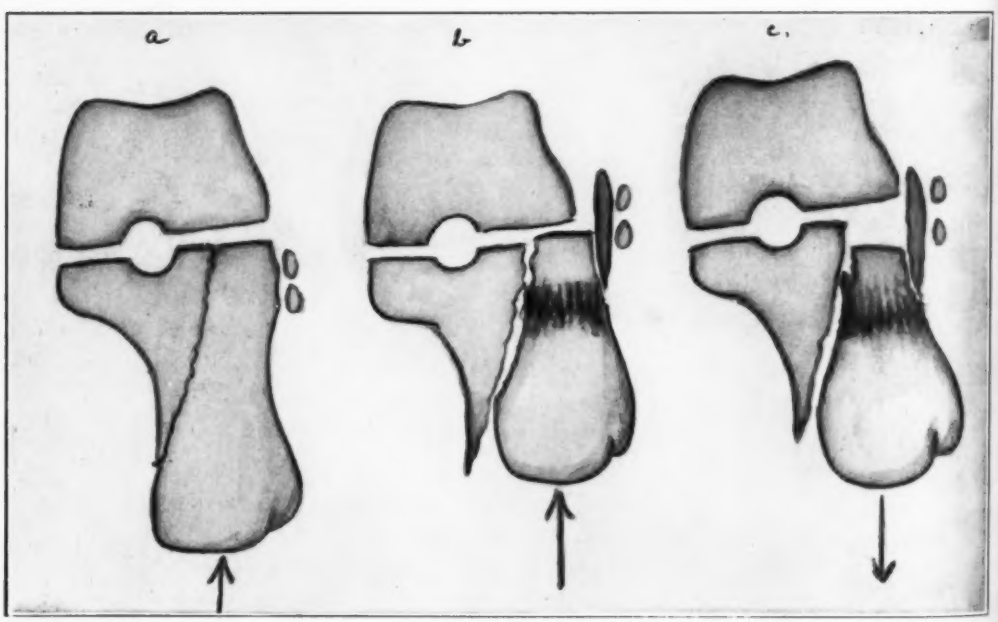

FIG. 1

Diagram showing the mechanism of comminuted fractures of the calcaneus.
a: Primary shearing fracture.
b: Compression and maximum dislocation at the moment of accident.
c: The lateral block, with impacted fragment due to secondary compression, recoils downward, forming a ledge across the surface of the joint.

the impact, while the articular portion is driven downward by the talus; the result is a vertical shearing fracture. If the foot is in varus position as it strikes the ground, a medial chip will be split from the tuber; if the foot is in valgus position, a lateral fragment will result. The medial type is infrequent, constituting, according to Watson-Jones, only 15 per cent. of all fractures of the calcaneus. The lateral type, which usually involves a large part of the tuber calcanei, has an incidence of about 25 per cent. The fragments are displaced forward and upward, in accordance with the direction of the causative violence. If the fragment of the tuber is large enough, the result will be a simultaneous compression and depression of the longitudinal arch. The depression may be indicated by the so-called "tuber-joint angle" of Böhler, which has been generally accepted as a standard for the evaluation of all fractures of the calcaneus. These two simple fractures offer no problems in mechanism or treatment. Their prognosis is favorable.

In most cases of lateral shearing fracture, however, the injury is not restricted to the tuber. The line of fracture starts from the medial side and runs laterally and upward; failing to reach the lateral surface of the tuber below the posterior facet of the talocalcaneal joint, it extends upward through the floor of the joint and splits it into two parts (Fig. 1, *a*). Sometimes the fracture line continues forward to split the calcaneocuboid joint, also. This type of shearing fracture is, therefore, intra-articular. Although it comprises the largest group (at least 50 per cent.) of all fractures of the calcaneus, the details of its structural relationships are little known. Roentgenograms fail to show clearly and completely its most important characteristic,—the intra-articular involvement. Its prognosis is unfavorable. Most patients who have sustained this type of fracture have a permanent disability of from 25 to 33⅓ per cent.

These observations led the author a few years ago to attempt to treat this type of fracture by arthrodesis of the subtalar joint. It was thought that arthrodesis would reduce the healing time and put the foot into a position in which it might be capable of bearing weight without becoming painful. These operations provided an opportunity of studying the structural details of the fracture, and led to certain observations which have been verified subsequently in a considerable number of cases.

The large fragment produced by lateral shearing was found to be separated from the medial, undisplaced portion by a fracture line which ran longitudinally through the posterior facet of the talocalcaneal joint, dividing its articular surface in such manner that at least half of it was on the lateral fragment. Within this large lateral fragment, however, an additional or secondary fracture of compression type was found, the articular surface and underlying bone having been driven down into the subjacent spongy bone. This assembly of the lateral block was often covered laterally by a small shell-like fragment of cortical bone. A strange and interesting fact, moreover, was that the extent of the compression of the articular fragment not only corresponded to the forward and upward displacement of the lateral block, but even exceeded it in depth. This created in the joint a *ledge*, which sometimes reached the height of about 10 millimeters. Moreover, the planes of the two portions of the fractured facet were as a rule not parallel, the ledge being higher in front than at the rear. The articular fragment was clearly outlined, with no sign of being crushed into the smaller fragments which are seen in other compression fractures, such as those of the lateral condyle of the tibia.

The mechanism underlying this extremely important feature of the topography of the fracture seemed mysterious. It was at first thought that the talus, at the moment of the accident, had been subluxated over the calcaneus and thereby exerted an uneven pressure, which was greater laterally than medially. However, this hypothesis was abandoned, because it did not explain the sharply outlined ledge within the joint.

Little by little the following explanation of the mechanism of fracture became apparent. As the lateral block is pushed forward and upward by the dislocating force, it meets the resistance of the posterior articular facet of the talus. Cartilage is driven vio-

lently against cartilage. If the force is great enough, the weaker part, which is the more mobile lateral fragment of the calcaneus with its smaller surface, is pressed together like a concertina. This compression corresponds exactly with the displacement of the heel, when it reaches its maximum at the time of the accident (Fig. 1,*b*). When the compressing force ceases, the lateral block recoils slightly; in addition, it is displaced by contraction of the Achilles tendon. The articular fragment, which has been pressed firmly into the underlying bone, follows the recoil in a direction opposite to that of the original compressing force. Its contact with the articular surface of the talus is lost, and the sharp ledge of the undisplaced articular surface of the medial calcaneal fragment is produced (Fig. 1,*c*).

Further observation showed that the secondary compression fracture of the lateral block was of two types:

1. In some cases the articular fragment was about 1.3 centimeters in height and equal to the articular surface in length (Figs. 2-A and 2-B). This fragment, impacted more or less deeply into the subjacent bone, consisted in itself of a well-defined, unbroken piece of bone, covered on its articular surface by intact cartilage. A separate shell-like

FIG. 2-A

FIG. 2-B

Fig. 2-A: Comminuted fracture, Type I, before reduction.
Fig. 2-B: After open reduction and filling with cancellous graft.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Comminuted fracture, Type II, before reduction.
Fig. 3-B: After open reduction and filling with cancellous graft.

fragment of the lateral cortex, attached to the sheath of the peroneal tendons, was often present.

2. Just as often, however, the upper fragment extended posteriorly to include the upper part of the tuber; the tuber was thereby split into two portions, which gaped apart posteriorly. Fractures of this type proved particularly convenient for treatment by open reduction, because of the size and shape of the fragment which supported the articular surface (Figs. 3-A and 3-B).

DIAGNOSIS

Close cooperation between surgeon and roentgenologist is essential for determining the nature of a fracture of the calcaneus, and for separating cases suitable for conservative treatment from those in which open reduction is necessary. Lateral as well as axial roentgenograms are, of course, always essential. Anatomical variations are considerable; the tuber-joint angle varies normally between 10 and 40 degrees, and the length and width of the fractured tuber cannot be measured with accuracy. Corresponding roentgenograms of the uninjured foot are, therefore, always necessary.

The posterior facet of the talocalcaneal joint, where the essential fracture is located, is, however, not easily demonstrable in roentgenograms. The joint surfaces are convex and slope laterally. A lateral roentgenogram, therefore, shows the inner part of the posterior facet, together with the medial and anterior facets, but completely fails to demonstrate the remainder of the joint. The sinus tarsi, however, is always visible, and the lateral portion of the posterior facet always extends forward to this landmark. An oblique lateral roentgenogram, taken from below and posteriorly, provides a clear projection of this portion of the joint as it reaches the posterior end of the sinus tarsi. In this roentgenogram a compressed fragment is visible, despite the background of the medial fragment, and is recognizable as a rather faint shadow. This is easily overlooked; it will probably go unnoticed unless the attention of the roentgenologist is directed particularly to it. In the axial roentgenogram, however, the compressed fragment appears more or less clearly. In any event, the ledge which interrupts the outline of the articular facet should always be visible (Fig. 4).

If the lateral block is large and its articular surface is deeply depressed, the talus

FIG. 4

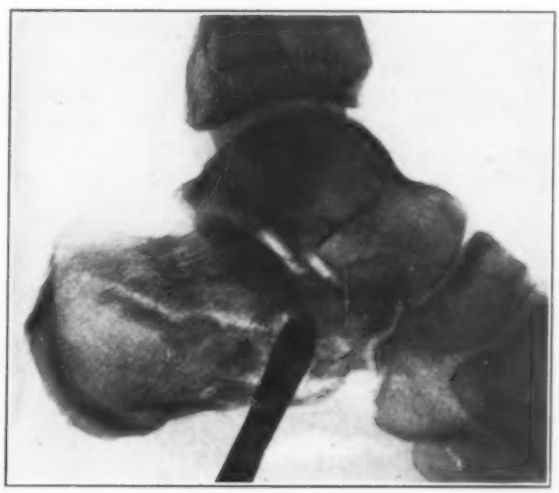

FIG. 5

Fig. 4: Axial view of the shearing fracture, showing compression in the lateral block. The ledge at the articular surface is visible.

Fig. 5: The compression cavity is visible after reduction of a depressed articular fragment by means of an elevator.

may rotate on its longitudinal axis to produce a lateral widening and subluxation of the ankle joint.

The surgeon should obtain the opinion of the roentgenologist on the following points: (1) whether a simple linear fracture or a combined linear and compression fracture is present; and (2) if comminution and compression are present, the size of the depressed fragment of the articular surface and the height of the ledge between the two parts of the articular facet should be determined.

TREATMENT

Double transfixion and traction, according to the method of Böhler, have apparently been accepted widely as the standard technique for the treatment of these fractures. The method is recommended without reservation, not only by German writers, but also by British and American authors, including Watson-Jones, Schofield, and Jaekle and Clark. Recently, however, Böhler himself fails to show enthusiasm for this method. In the sixth edition of his textbook, he recommends in certain cases reduction with the aid of the Phelps-Gocht clamp, a rather complex instrument which secures a three-point grip on the foot. The reduction is then stabilized by the introduction of a pin from the back of the heel, according to the technique of Westhues.

FIG. 6

Diagram showing the defect under the reduced fragment of the articular surface; this is formed by the compression of spongy bone.

In 1932, Lenormant and Wilmoth described a method of open reduction similar to that used by the author. They explained the depression of the articular surface as being the result of fracture of weak subjacent cancellous bone, containing relatively few trabeculae. Other surgeons have attempted open reduction and osteosynthesis by means of metal pins. Open reduction, however, has never been adopted widely, the apparent reason being that it has offered little advantage, owing to the difficulty of maintaining a stable reduction.

In order to shorten the period of total disability in cases of fresh comminuted fracture, the author decided at first to try primary arthrodesis of the talocalcaneal joint. This operation, carried out on three patients, was not wholly satisfactory. The exposure was necessarily extensive and impaired the nutrition of the fragments. The osseous substance, which had already been compressed laterally by the fracturing force, was further reduced by removal of the articular surfaces; it was, therefore, difficult to avoid excessive valgus deformity. The result in each case was a fused subtalar joint with a valgus deformity of the foot. The functional results were moderately good.

These operations demonstrated that, contrary to previous conceptions, the depressed fragment bearing the articular surface was sharply outlined, firm, and stable. By means of an elevator, introduced into the compressed substance beneath it, this fragment could be levered upward and forward to restore the normal structure of the joint (Fig. 5). If, however, the entire lateral block was reduced by traction on a wire transfixing the tuber, the impacted articular fragment could be seen to move downward and backward, heightening the intra-articular ledge and thereby increasing the displacement within the joint. This demonstrated clearly that commonly used methods of reduction actually have an unfavorable effect on the essential factor of the articular injury. It was evident, also, that the normal structure of the joint and the normal contour of the calcaneus could be restored by open reduction with a moderate amount of surgical exposure.

An operation of this type has now been carried out in twenty-three cases. Being based directly on the details of the injury, it is divisible logically into three steps: (1) reduction

FIG. 7-A

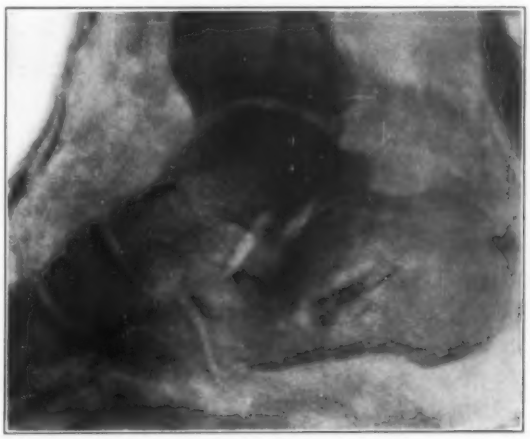

FIG. 7-B

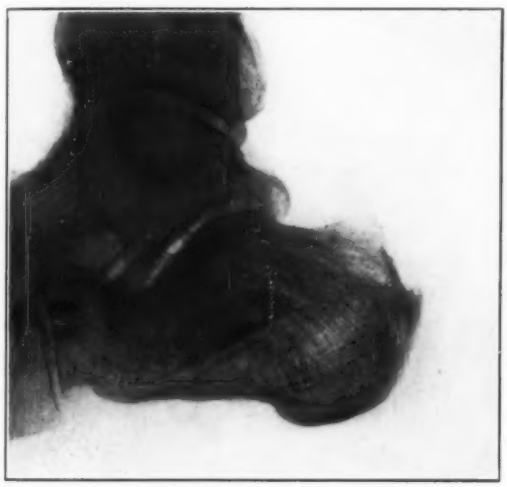

FIG. 7-C

FIG. 7-D

Fig. 7-A: Comminuted fracture, Type II, before reduction.
Fig. 7-B: After open reduction and filling.
Figs. 7-C and 7-D: Lateral and axial views, one year after operation.

of the entire lateral block of the shearing fracture; (2) reduction of the secondary compression fracture, involving the articular surface; and (3) filling the bony defect, which results from elevation of the articular fragment to its normal position.

A curved incision, six centimeters in length, is made beneath the lateral malleolus. The sheath of the peroneal tendons is incised, and the tendons are displaced forward. At the proximal portion of the peroneal sheath, the incision is deepened to divide the middle part of the fibulocalcaneal ligament and expose the talocalcaneal joint. If the foot is carefully dislocated into a varus position over a wedge, it is possible to look into the joint and to observe and measure the pathological ledge between its facets.

A transfixion wire is drilled into the angle between the point of the tuber calcanei and the Achilles tendon, and is tightened into a bow. Traction downward and backward will now reduce the lateral block of the shearing fracture without difficulty. An elevator is introduced into the compressed substance under the articular surface, and is used to lever this fragment into position until the intra-articular ledge is level. The reduction, however, is extremely unstable. If the traction and the elevator are released, displacement recurs.

When the fragments are held in the position of reduction, a large defect formed by the compression of spongy bone appears beneath the articular fragment (Fig. 6). The presence of this defect explains a frequent end result of the conservative treatment of

fractures of the calcaneus. After temporary reduction (probably the articular fragment is never perfectly repositioned), the bone collapses to produce traumatic flat-foot in the valgus position.

The compression cavity, which is usually about the size of the end of one's thumb, is next measured. A transplant, taken from the crest of the ilium, is shaped to correspond to the cavity; it should be slightly larger than the defect in the calcaneus. This graft is hammered into the cavity by means of a tamp.

The reduction will now be quite stable. The fragment of the articular surface is pressed firmly upward against the articular surface of the talus; the lateral block shows no tendency toward dislocation. The transplant serves as a key for locking the reduction. Postoperative roentgenograms show that the normal contour of the calcaneus has been restored (Figs. 2-A, 2-B, 3-A, 3-B, 7-A, 7-B, 7-C, and 7-D).

For postoperative immobilization, a short leg cast is used; transfixing pins are unnecessary. Two to four days after operation, the patient is allowed to walk on crutches without bearing weight on the injured foot. After twelve weeks, the plaster is replaced by a zinc-paste stocking and a strong shoe with a longitudinal arch support.

RESULTS

This operation has been carried out in twenty-three cases of fracture of the calcaneus with a depressed articular fragment. Nineteen of the patients were men and four were women. Their ages ranged from thirty to seventy-two years. In twelve cases a Type I injury was present; in eleven cases it conformed to Type II. Two of the patients had simple linear fracture of the opposite calcaneus. In one case the ankle joint was destroyed by a central compression fracture of the lower end of the tibia.

No unusual technical difficulties were encountered during these operations. In all cases the convalescent period, in striking contrast with that after treatment by transfixion and traction, offered remarkably little inconvenience. It was of great advantage that the patient was not confined to bed, but could be up a few days after operation.

Follow-up examinations of these patients, who were treated between May 1944 and March 1946, have shown remarkably favorable results. All of the patients were back at their previous work from four to eight months after the operation. The majority have shown, when examined from six months to two years after operation, painless pronation-supination in the subtalar joint of from 15 to 30 degrees (one-quarter to one-half the normal range). In one case, which must be regarded as a failure, a painless mobility of only 5 degrees is present; one presents painless ankylosis in good functional position. In all cases the shape of the longitudinal arch is the same as that of the uninjured foot. Most surprising and encouraging is the fact that the mobility is really painless; in this respect, these cases form a sharp contrast to those treated by conservative methods.

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SLIPPED EPIPHYSIS IN THE ADOLESCENT HIP

A Reconsideration of Open Reduction*

BY PAUL H. MARTIN, M.D., JACKSONVILLE, FLORIDA

A review of the literature on slipping of the upper femoral epiphysis impresses one with the unsatisfactory results of treatment, especially of the severely displaced epiphysis which requires reduction. Almost uniformly, reports show good results in the cases with a minimal degree of slipping, but a depressing percentage of poor results in those with severe or complete slipping. Therefore, it seems important to report any refinement of method which gives promise of improving the prognosis in this discouraging condition.

If the problem of treatment were only that of correcting deformity, the simple measure of intertrochanteric osteotomy after union of the epiphysis would suffice. This procedure might still be useful in the occasional case in which the displacement of the neck is mostly anterior (anteversion), and traumatic arthritis from impingement of the neck against the acetabulum has, therefore, not supervened. In most cases, however, this fortunate condition does not obtain, and the desirability of early reduction of the epiphysis is made obvious.

In most cases, so-called traumatic arthritis is the late secondary result of ischaemic necrosis of the capital epiphysis. This complication is to be feared more than deformity alone, and is the cause of most of the poor results in any reduction treatment, open or closed. However, gross aseptic necrosis seldom occurs in untreated cases. Therefore, the treatment must cause the necrosis by further injuring the blood supply of the epiphysis. In too many instances, treatment thus defeats itself. Many excellent reductions of a displaced epiphysis are followed by necrotic changes, which always end in limitation and, later, in osteo-arthritis and even ankylosis. Preservation of the blood supply of the epiphysis is the crux of the problem of treatment.

The blood supply to the capital epiphysis of the femur can come from only three sources:

1. A few small vessels which penetrate the cartilage plate from the neck.
2. The vessels in the ligamentum teres.
3. The vessels in the periosteum of the neck, which in childhood is much thicker and more vascular than in the adult.

The vessels penetrating the cartilage are, of course, destroyed when the epiphysis slips. The vessels in the ligamentum teres are small and may be absent. The periosteal vessels are also torn, at least on the anterior aspect of the neck, as the head slips posteriorly. Thus, at best, the blood supply of the epiphysis is meager after slipping occurs. However, avascular necrosis is practically never encountered in untreated cases, although occasionally we see degenerative changes in the articular cartilage which may be secondary to deficient circulation in the underlying bone. In such cases, the roentgenogram shows narrowing of the joint space, but no change in the density or contour of the head of the femur. When this narrowing of the joint is present, no treatment will give good results; and, in fact, ankylosis may occur with or without treatment. It is the author's belief that often the treatment has been blamed for poor results which are actually due to this pre-existing degenerative condition (Figs. 1-A and 1-B).

During the last seven years, the author has observed and treated by various methods, twenty-six patients with slipping of the capital epiphysis (thirty-three hips). These experiences have led to certain conclusions concerning the probable cause of many of

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

FIG. 1-A

H. S. Roentgenogram shows narrowing of joint space without gross necrotic changes in the epiphysis. The significance of this was not appreciated at the time of treatment. Compare with normal right hip.

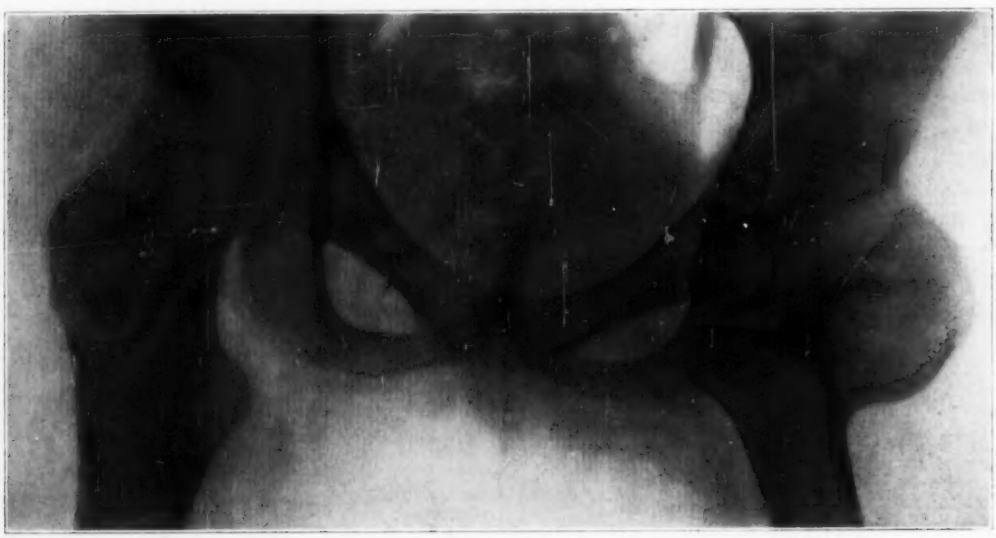

FIG. 1-B

Ankylosis occurred within six months after intertrochanteric osteotomy. The condition ultimately progressed to solid bony ankylosis without roentgenographic evidence of necrosis. In such a case, any form of treatment will fail.

the bad results heretofore obtained, and to the development of a technique of treatment which is thought to avoid some of the pitfalls of the past, through meticulous respect for the remaining blood supply of the epiphysis.

There seems little doubt that injudicious manipulation to accomplish closed reduction, and surgical trauma in open reduction, have been the sources of most of our difficulty. Closed reduction should be condemned, except for a gentle manipulation to reduce an *acute* displacement. Manipulation should not be expected to effect reduction of an epiphysis which has slipped gradually or one which has been displaced for several weeks or months; for the epiphysis is firmly adherent to the neck by fibrous tissue and sometimes by callus, while it is anchored to the acetabulum by only the ligamentum teres. Usually manipulation of such a hip not only fails to accomplish its purpose, but it damages the ligamentum teres. Loss of this source of blood supply may alone lead to aseptic necrosis

in certain cases, and in any case it makes later open reduction more hazardous and uncertain. Even if the manipulation is successful, the remaining periosteal attachments of the epiphysis must be torn to allow the reduction. Then necrosis will surely occur, unless by chance there remains sufficient circulation through the ligament.

In those cases requiring open reduction, great care should be taken to preserve both the ligamentum teres and the periosteum on the posterior and inferior surfaces of the neck. The epiphysis should not be entirely detached from the neck in this region. If both the ligamentum teres and the postero-inferior portion of the periosteum are uninjured, the blood supply should be practically the same as before operation, and the head should survive.

It is generally and logically accepted that, if the displacement of the epiphysis is more than one centimeter, either downward or posteriorly, reduction is necessary. For practical purposes these severe displacements should be divided into two groups: (1) the acute traumatic cases, and (2) the cases with gradual slipping.

There undoubtedly are some purely traumatic separations of the capital femoral epiphysis. These generally are in older patients who sustain severe wrenching injuries of the hip. These displacements are always acute, usually complete, and probably should be considered as fractures, like traumatic epiphyseal separations in other bones. In these cases, if symptoms have been present for less than two weeks, manipulatory reduction may be tried. Often reduction can be accomplished by gentle traction and internal rotation, followed by or combined with abduction. These acute cases should be the *only exceptions* to the rule against manipulation. The reduction must be easy, or attempts should be abandoned. Vigorous manipulation, as by the Leadbetter manoeuvre, or strong traction on the orthopaedic table should not be used. If the epiphysis can be reduced easily, it should immediately be fixed by a Smith-Petersen nail. Excellent results will be obtained in this type of case if only the hips in the *acute* phase are manipulated (Figs. 2-A and 2-B).

If the slipping has been more gradual, or in the acute cases of more than two weeks' duration, open reduction should be done *without any preliminary trial of manipulation.* It is striking that in most reported series, if the acute cases are excluded, the percentage of poor results is about the same from either closed or open reduction. This may indicate that much the same damage is done by both forms of treatment. It is the author's opinion that both methods often fail because of further damage to the blood supply of the epiphysis, chiefly the postero-inferior periosteum. Of course, the present statistical picture is

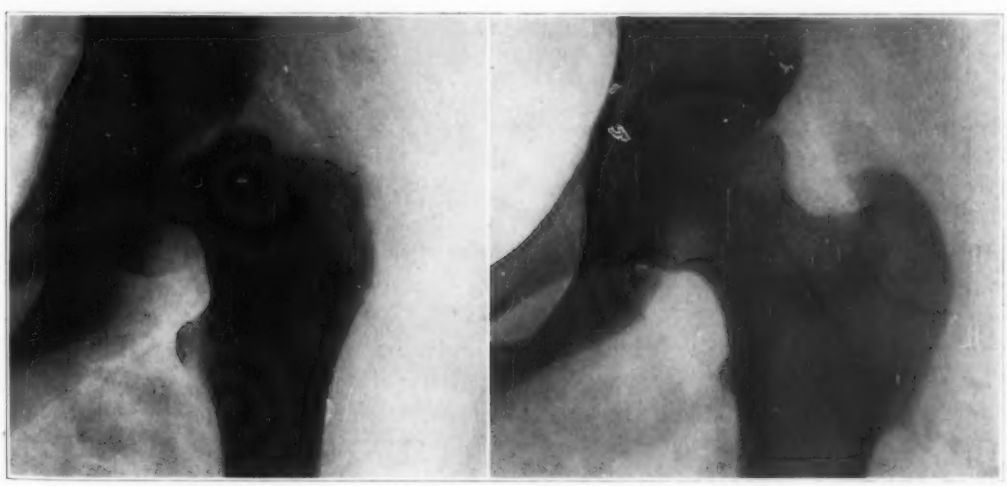

FIG. 2-A FIG. 2-B

Fig. 2-A: O. K. In this case of acute traumatic slipping, reduction was achieved by manipulation and the epiphysis was nailed by "blind" technique two days after slipping.
Fig. 2-B: Shows result twenty-seven months later. Function was normal.

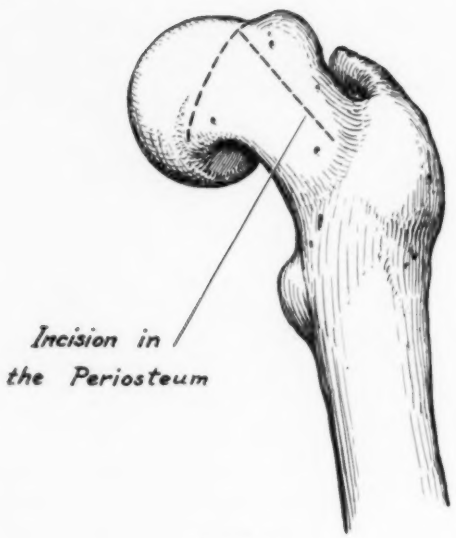

FIG. 3-A

The whole lower extremity is prepared and draped to permit free manipulation. The orthopaedic table is not used. The hip is exposed by the Smith-Petersen incision, and the capsule is divided by a T-shaped or L-shaped incision, close to the rim of the acetabulum.

Fig. 3-A: Shows the T-shaped incision in the periosteum. The transverse portion is immediately distal to the rim of the epiphysis; the longitudinal limb should be slightly above the mid-line of the neck.

Fig. 3-B: The periosteum is carefully elevated, without tearing. It is not necessary at this stage to elevate completely around the neck. The bone should be removed piecemeal rather than by through-and-through osteotomy, with danger to the posterior portion of the periosteum. The last of the bone and callus should be carefully removed, to preserve the posterior and inferior portions of the periosteum.

Fig. 3-C: After the neck has been entirely freed from the head and the periosteum, and has been sufficiently shortened to allow easy reduction into the head, a guide wire for a Smith-Petersen nail is introduced through a lateral incision and drilled blindly through the neck until the point barely emerges in its center.

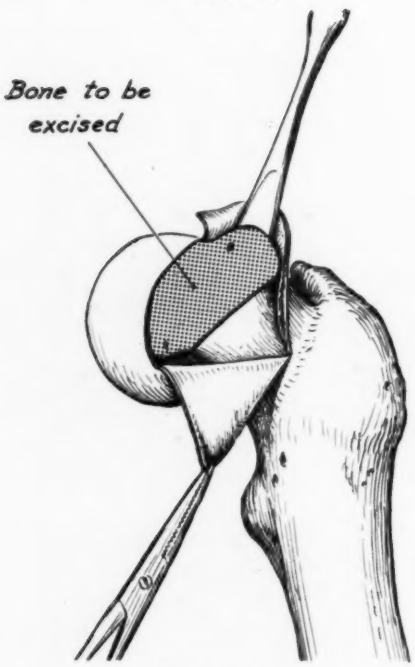

FIG. 3-B

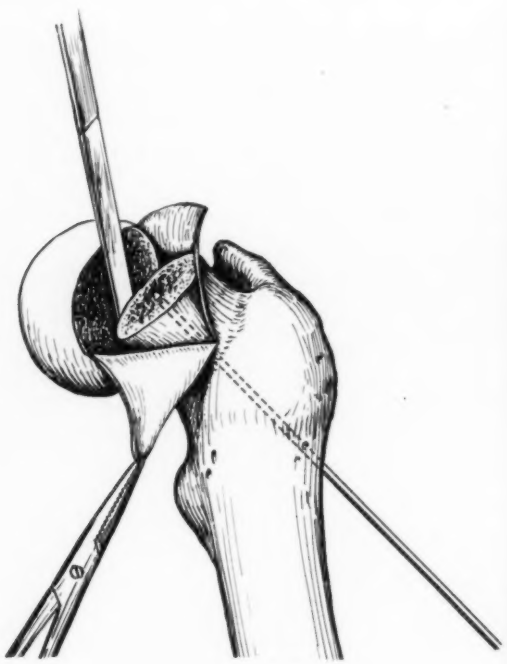

FIG. 3-C

confused, because heretofore most patients operated upon have first had unsuccessful manipulation. Therefore, it is impossible to determine how many of the poor results have been caused by the operation alone. Any study of operative results in which manipulation has also been tried must be very inaccurate indeed. However, it is to be hoped that within a few years a large series of cases can be accumulated in which no preliminary manipulation has been done; and in which, at operation, the periosteum on the posterior and inferior aspects of the neck has been carefully preserved both from actual tearing and from tension. The method we are advocating does this, and so far it has given very gratifying results.

This is not a new operation, but only a refinement in technique, based on the principles just indicated. It is very similar to the open reduction described by Wilson in 1924, but for one important particular: Except possibly in the acute cases of less than two

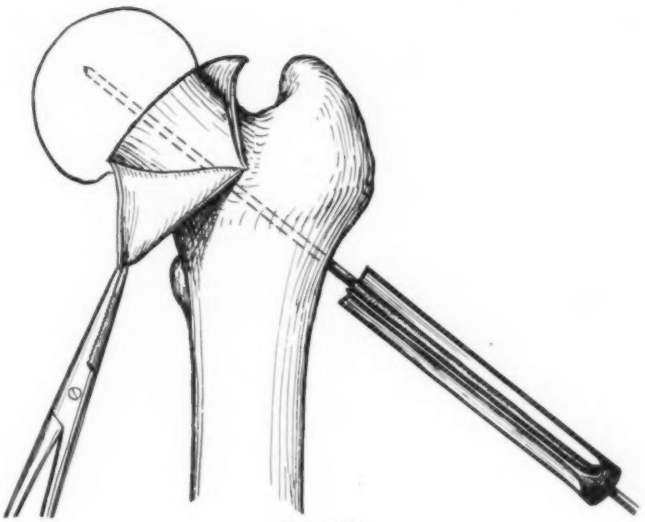

FIG. 3-D

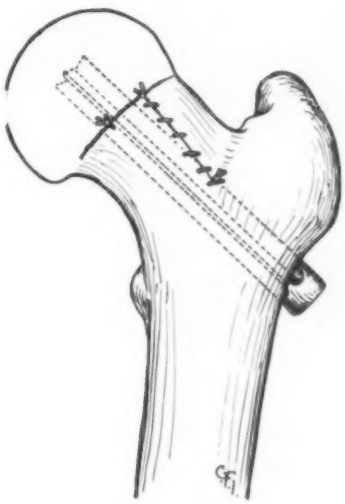

FIG. 3-E

FIG. 4-A

FIG. 4-B

Fig. 3-D: The neck is then reduced into the head, a thin skid being used to steady the head, but not to pry. The guide wire is then drilled in 1.5 centimeters farther. By subtracting the protruding portion of the wire from the length of a similar wire, a nail of appropriate length may be selected.

Fig. 3-E: The Smith-Petersen nail is driven by many light blows of the mallet, rather than by fewer heavy blows. The neck must be firmly impacted against the head. The periosteum is closed by a running catgut suture, and tacked to the edge of the epiphysis by several interrupted sutures. Thus the neck is again completely covered with synovial membrane. The incision in the capsule is closed carefully.

Fig. 4-A: J. C. B. Complete slipping with callous union.

Fig. 4-B: Result nine months after open reduction, just before the nail was removed. Function was practically normal.

Fig. 5-A: J. K. Patient had complete slipping, with fibrous union; symptoms of about three months' duration.

FIG. 5-A

weeks' duration, no attempt should be made to prize the head up onto the neck; but sufficient bone should be removed on the anterior and superior aspects of the neck to allow the neck to be easily reduced into the head. This amounts to a cuneiform osteotomy, even in recent cases. We believe that this step avoids tearing or even excessive tension on the posterior and inferior periosteal vessels, as would happen if a posteriorly displaced epiphysis were prized forward onto an unshortened neck; this is especially true if several weeks have elapsed, allowing time for the periosteum to shorten and even for callus to form in the posterior angle between the neck and the epiphysis.

Gentleness is just as important in open manipulation of the epiphysis as it is in closed reduction. The periosteum should be incised and carefully elevated from the neck, and the osteotomy and reduction should be carried out strictly within the periosteal tube. The periosteum in these cases strips up easily, and this technique is perfectly feasible. After the epiphysis has been realigned, it is fixed by a Smith-Petersen nail, introduced over a guide wire through a smaller lateral incision. The periosteum is carefully sutured and attached to the edge of the epiphysis, completely covering the neck again with synovial membrane (Figs. 3-A, 3-B, 3-C, 3-D, and 3-E).

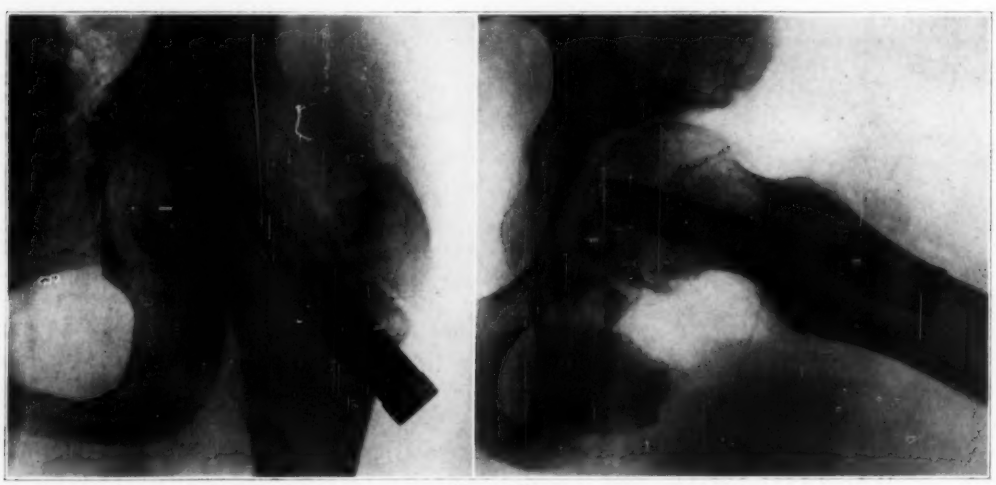

FIG. 5-B
Roentgenograms taken seven months after open reduction.

FIG. 5-C
Twenty-eight months after open reduction, and about one week after removal of nail.

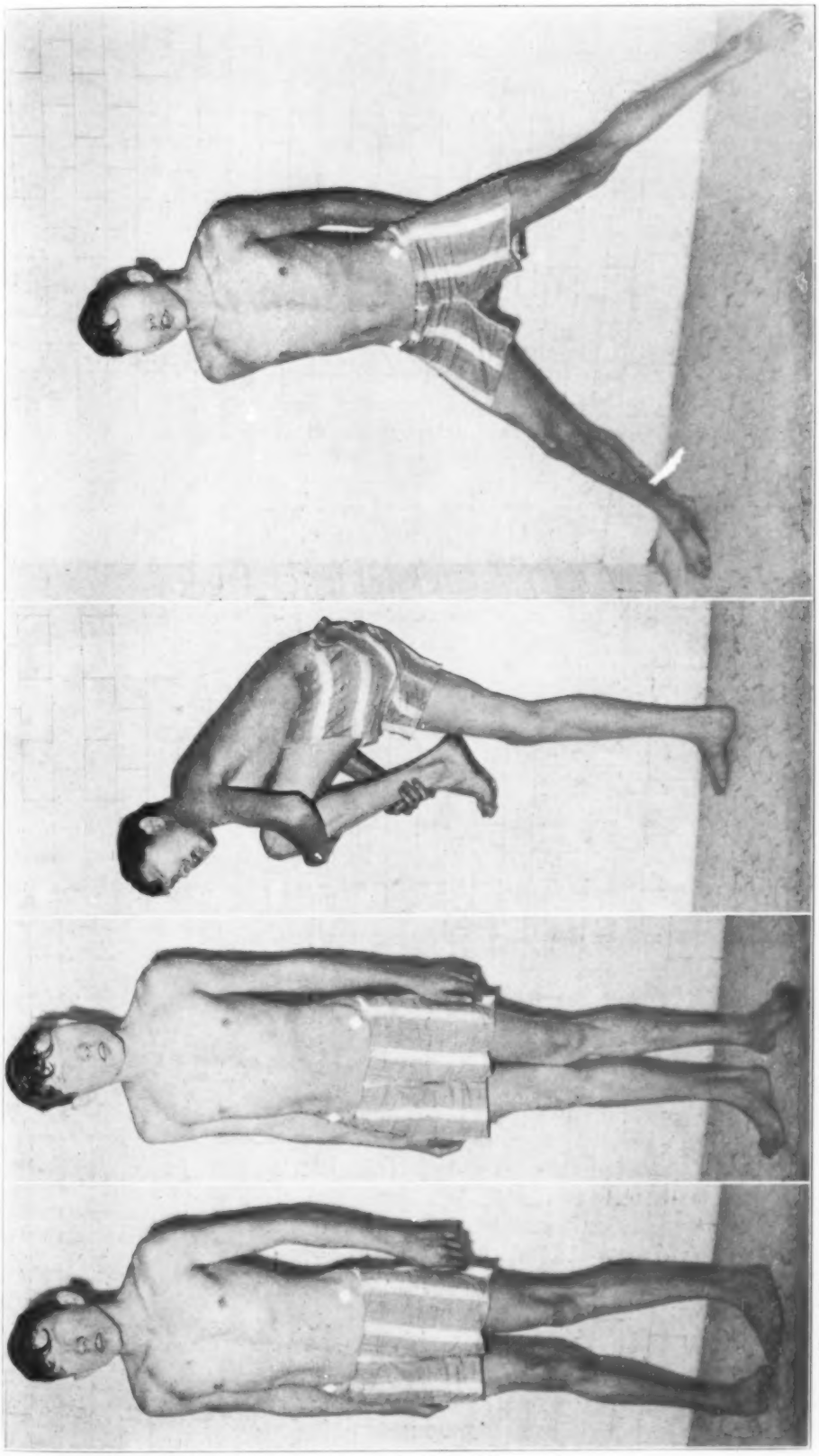

FIG. 5-D FIG. 5-E FIG. 5-F FIG. 5-G

Showing range of motion of left hip, twenty-eight months after open reduction. Function is practically normal, but patient has shortening of one inch.

FIG. 6-A

G. R. This patient had complete slipping, with union by bony callus. Symptoms had been present for about six months.

FIG. 6-B

Roentgenograms taken six months after open reduction.

FIG. 6-C

Showing hip fourteen months after operation, just after nail had been removed.

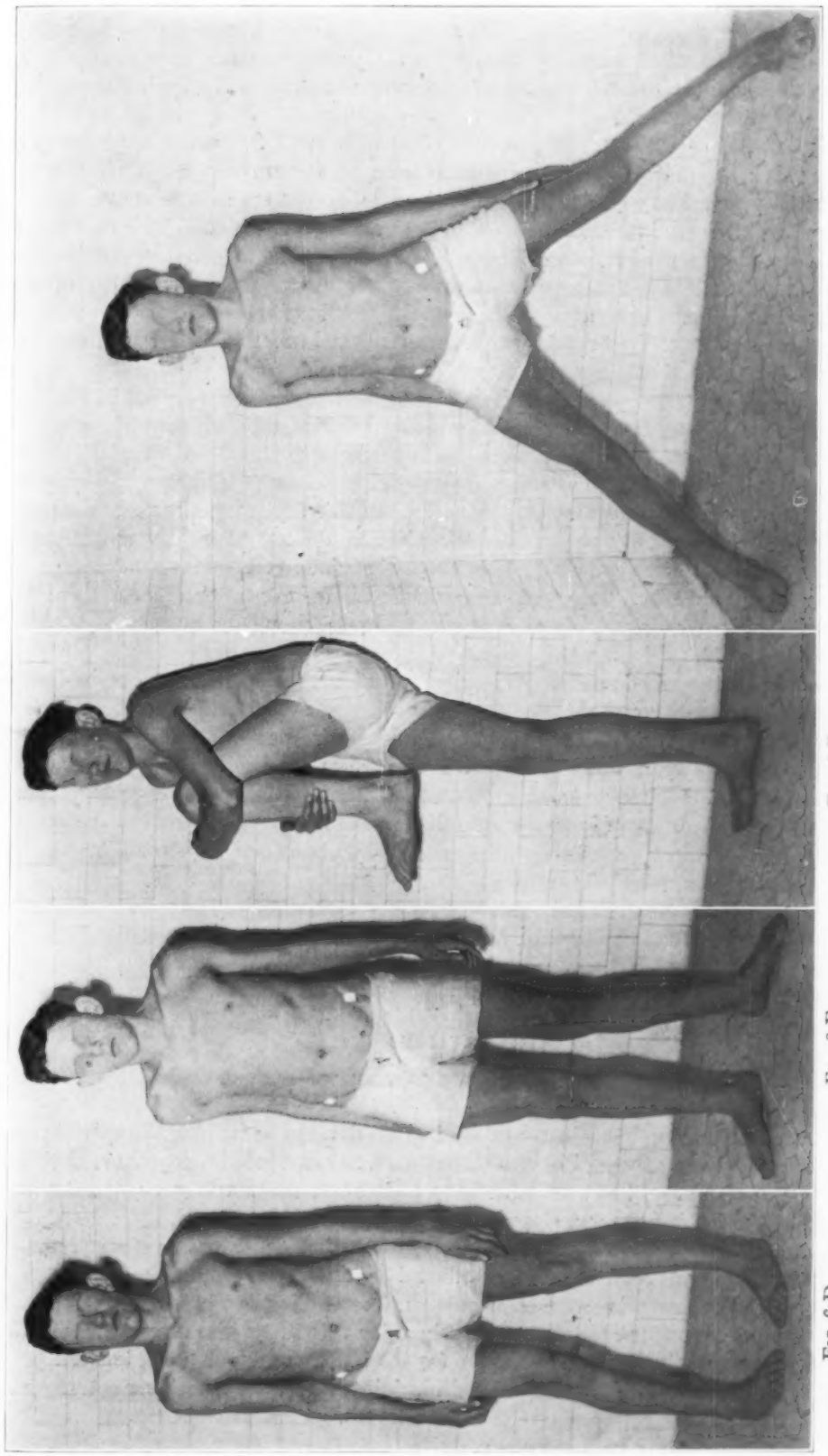

FIG. 6-D FIG. 6-E FIG. 6-F FIG. 6-G

Showing motion of left hip, fourteen months after open reduction. Function was excellent; shortening of one-half inch was present.

This method is equally applicable when the epiphysis is united by bone in a completely displaced position, although in these older cases somewhat more bone from the neck should be sacrificed, so as to avoid excessive tension on the periosteum when the reduction has been made. A seemingly radical sacrifice of bone will not shorten the limb more than an additional quarter of an inch.

The author has used this method in eight cases since 1943. One case is too recent to be included in this series. The time since operation averages twenty-one months in the other seven, with the oldest thirty-nine months, and the most recent ten months. Some may say that the whole series is too recent to be used in determining final results. This may be true in regard to possible future arthritic changes, but I believe that we are past the danger of aseptic necrosis, which is the cause of most of the poor early results and is also the chief factor in the development of serious late osteo-arthritis. Six of these seven patients should be classified as having excellent results, with almost normal function as regards limp, pain, and motion. In one of them, however, trouble may develop later, although it has been thirty-nine months since her operation. Four months after operation, necrosis of the upper anterior quadrant of the head developed, possibly because the nail may have cut the blood supply to this area. There is now some incongruity of the head and, despite excellent present function, osteo-arthritic changes may develop many years hence. In only one case has a poor result followed the open reduction. In this one, the nail was too long and worked through the head, gouging a defect in the acetabulum before the situation was discovered and the nail was removed. This girl, twenty-one months after operation, has marked limitation and a bad limp from an adduction deformity of the hip. Arthroplasty will undoubtedly be required. This poor result, however, should be attributed to faulty technique rather than to the method.

In 1944, Green described an almost identical technique, and reported two cases, treated in a similar manner with excellent results. If our seven cases are added to these two, we would have eight excellent functional results in nine cases so treated. The only poor result was due to a technical error, and not to necrosis. In only one of these cases (our first) has any degree of necrosis occurred. As just mentioned, there is in this case excellent present function, but the probability of later arthritic changes. Complete displacement was present in all of these cases, and three of the author's cases had bony union (Figs. 4-A, 4-B, 5-A through 5-G, and 6-A through 6-G).

This operation is difficult and should not be undertaken lightly. The technique is exacting and tedious, and will test the ability of the most capable orthopaedic surgeon. Nonetheless we believe it to be worth while in this group of cases, always so discouraging when treated by other methods.

CONCLUSIONS

1. Most poor results are caused by improper treatment, and are due chiefly to avascular necrosis in the epiphysis.

2. Necrosis in the epiphysis is caused by further damage to its blood supply through the ligamentum teres and the periosteum on the posterior and inferior aspects of the neck.

3. Manipulation should be condemned except in acute traumatic cases, and it should be gentle. If reduction is not easy, closed methods should be abandoned.

4. Patients in the so-called preslipping stage and those with minimal slipping (less than one centimeter) are best treated by nailing *in situ* without reduction.

5. When displacement is more than one centimeter, and is gradual or has existed longer than two weeks, open reduction should be done without preliminary manipulation. This must be accomplished with due respect for the blood supply of the epiphysis.

6. In old united cases, if there is a good hip joint, intertrochanteric osteotomy may be beneficial. Later in life, arthroplasty offers much improvement for the old arthritic hips and especially for the cases with ankylosis.

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OPERATIVE THERAPY FOR SLIPPED UPPER FEMORAL EPIPHYSIS

AN END-RESULT STUDY *

BY CARL E. BADGLEY, M.D., A. S. ISAACSON, M.D., J. C. WOLGAMOT, M.D., AND J. W. MILLER, M.D., ANN ARBOR, MICHIGAN

The treatment of displacement of the upper femoral epiphysis has generally been regarded with dissatisfaction and uncertainty. During the past twenty years the conservative therapy, consisting of manipulative reduction or reduction by traction and external fixation, has been superseded by internal fixation, frequently associated with open reduction. The early optimistic reports of the results of such operative therapy have not been substantiated in many clinics. Aseptic necrosis and stiff hips have resulted so frequently that the present trend is again toward conservative therapy. Common practice consists of a trial of skeletal traction and correction of position by abduction and internal rotation for a period of several weeks; if successful, this position is maintained until fusion occurs. If failure of correction is obvious, trochanteric osteotomy is a favorite procedure. The trochanteric osteotomy is intended primarily to correct the external-rotation deformity and to alter the position of the head so as to improve the mechanics of the joint.

For a number of years, since Wilson's operative replacement of the malunited upper femoral epiphysis, the authors have utilized the following postulates as a guide in the treatment of displacement:

1. A displacement of not more than one third of the diameter of the femoral epiphysis, as observed primarily in the lateral roentgenographic view of the hip joint, has been accepted as a satisfactory position. These hips, and those showing displacement of less than one third the diameter or no displacement (the "preslipping" stage) have been treated by internal fixation without any attempt at correction, to prevent progression of the deformity.

2. Displacement of the upper femoral epiphysis beyond this extent, usually associated with deformity and disability, requires improvement of the position of the epiphysis in its relationship to the neck.

3. Skeletal traction has been used for the reduction of the displacement. Should a

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

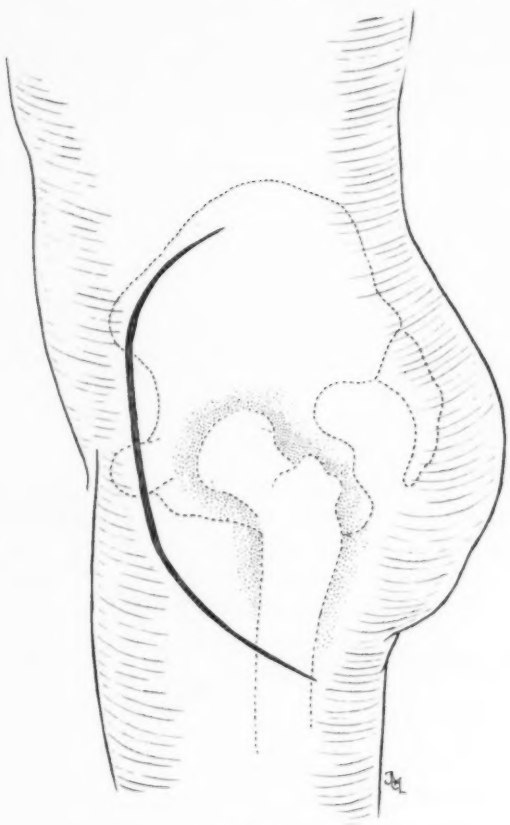

FIG. 1

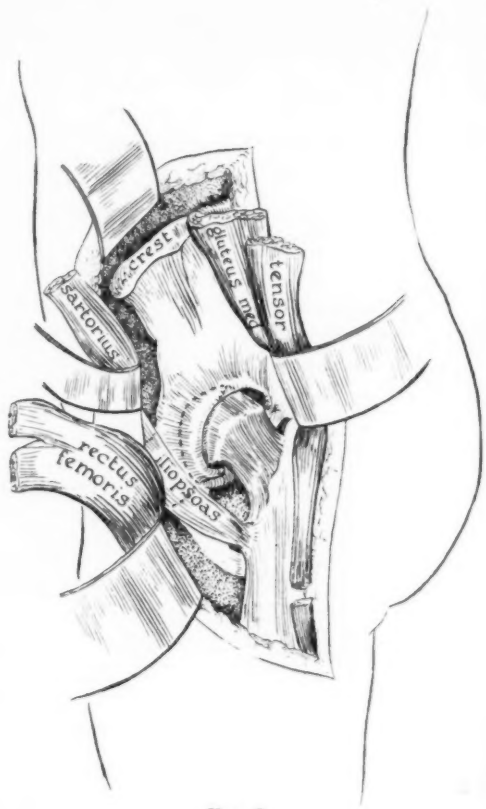

FIG. 2

satisfactory reduction result, its maintenance by internal fixation until the femoral epiphysis has become fused has been the most successful method of treatment. The acute traumatic type or the chronic type of slipping, suddenly completed by trauma, is usually corrected readily by this method; *mild* manipulation may be successful to complete the correction.

4. Unsuccessful skeletal traction necessitates open reduction of the displaced epiphysis. Not infrequently, removal of a wedge of newly formed bone anteriorly has been required to allow proper realignment. Pin or screw fixation to maintain correction until fusion occurs has been advisable.

5. The ultimate fate of the neglected and displaced upper femoral epiphysis is most certainly degenerative arthritis. Correction or prevention of the displacement has been the rule of therapy. Correction, if the epiphyseal line is still open and active, has been made intracapsularly at the site of the lesion. The subtrochanteric or intertrochanteric osteotomy has been reserved for the patient with a malunited, fused upper femoral epiphysis and a hip which has maintained fair or good motion, but has an external-rotation deformity.

This thesis is based upon the rationale of therapy, directed toward prevention of displacement of the epiphysis in the early phase by internal fixation; in the later stage of more marked displacement, therapy is directed toward correction of the deformity where it has occurred at the epiphyseal juncture with the neck, and maintenance of the correction by internal fixation. The authors have felt that correction by osteotomy in the trochanteric region did no more than produce temporary improvement, as the primary pathological condition was not corrected. The end results have been reviewed from time to time.

Although failures and disappointments have followed this program of therapy, we

have felt that the percentages of success have justified a continuance of this scheme. An end-result study is presented of the operations on seventy-eight hips, which represent various stages of epiphyseal displacement in sixty-six patients (twelve, or 18 per cent., having bilateral involvement), all of whom were treated surgically in accordance with the postulates listed. Two of these patients, without previous treatment, entered the Clinic because of extensive degenerative arthritis, producing incapacitating symptoms, for which Vitallium-cup arthroplasties were performed initially. These two cases illustrate that the arthritis is not necessarily the fault of an operative procedure, but may develop spontaneously in this peculiar lesion. Because of marked deformity and fixation of the hip, a Whitman reconstruction operation was performed in a third case, early in this series. The remaining sixty-three patients or seventy-five hips were operated upon as follows:

Open reduction was carried out on thirty-four hips for a malunited epiphysis; this required the removal of an anterior cuneiform wedge of bone. This overgrowth of bone lies between the displaced epiphysis and the neck of the femur. Fixation was obtained by means of a Smith-Petersen nail or by two screws.

Eleven hips were treated by open operation; an osteotomy at the epiphyseal site was performed for correction of the deformity, and reduction was maintained by external fixation,—namely, a plaster spica.

Four hips were treated by open operation with a simple osteotomy to correct the relationship between the epiphysis and the neck, followed by internal fixation.

Six patients were treated by closed reduction with traction, aided, if necessary, by very gentle manipulation. After satisfactory position had been obtained, blind nailing or screw fixation was employed.

Sixteen hips were fixed internally, without any attempt being made to correct a minor displacement.

Four hips were treated by means of the subtrochanteric type of Schanz osteotomy.

In view of the unsatisfactory results of open operative corrections reported to us by friends, the possibility of trauma from inadequate exposure has been suspected. The importance of an adequate exposure to the head of the femur should be stressed. The backward and downward displacement of the epiphysis makes exposure of the head by the ordinary procedures very difficult.

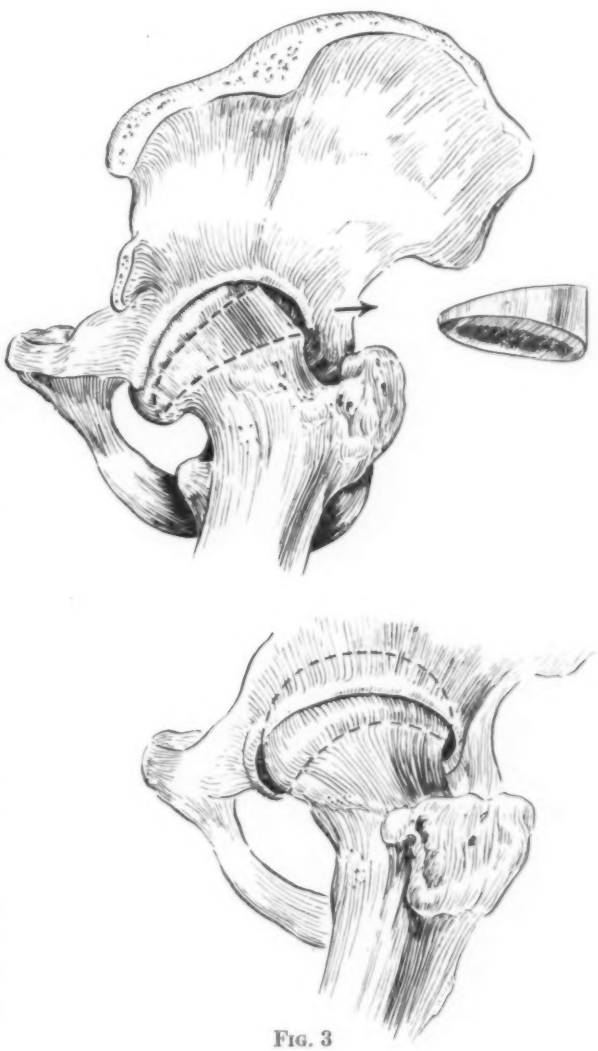

FIG. 3

By the use, however, of the approach (Fig. 1) described by Smith-Petersen for the Vitallium-cup arthroplasty, in which the iliopsoas is exposed and retracted

medially, an excellent view of the anterior portion of the acetabulum can be obtained (Fig. 2). It is then possible to achieve a very satisfactory exposure of the head and neck of the femur, and to observe the deformity. The line for the osteotomy, if malunion has occurred, is recognized, and the plane for the osteotomy can be determined without severe retraction or levering within the joint to displace the head and neck outward. If possible, the labrum glenoidale should be preserved.

The abnormality usually demonstrated by this approach in the stage of chronic slipping is an extension of the periosteum of the neck into a fibrocartilaginous-like material, covering a new-bone formation, which fills the interval between the displaced epiphysis and the neck of the femur. The new-bone growth is most excessive anteriorly and superiorly. Union is usually sufficiently solid so that an osteotomy is necessary to free the epiphysis. Sharp demarcation of the epiphyseal line is not obvious, and, in the selection of the osteotomy site, it is essential to differentiate the true cartilage border from this fibrocartilaginous covering of the new-bone formation.

It is important not to remove the periosteum too freely from the neck. Anteriorly, however, it should be stripped, in order to find the osteotomy site. Posteriorly, it should not be stripped from its attachment to the epiphysis, so that vascularity may be maintained.

A transverse osteotomy is performed at the juncture of the true cartilage of the head with the neck. The epiphysis and neck are thus freed. Speed, of Memphis, has made an important addition to facilitate reduction and accurate reposition. With a sharp instrument inserted into the posterior portion of the freed epiphysis, the head is readily turned anteriorly and upward from its posterior position. The neck is then fitted to the epiphysis. Frequently it has been found necessary, in order to secure good approximation, to remove from the neck a wedge of bone (Fig. 3), with its base anterior and superior, to obtain proper reduction. The neck is then reduced in its relationship to the epiphysis by internal rotation and abduction of the thigh, which usually produces excellent realignment.

In former days, external fixation in a plaster spica was relied upon to maintain this correction; this method has proved unsuccessful in 50 per cent. of the cases. Internal fixation by means of the Smith-Petersen nail or screws has now been applied routinely. Although there is little difficulty in driving a Smith-Petersen nail blindly into the epiphysis in the preslipped stage, or into the epiphysis which is mildly displaced, great difficulty has been experienced in penetrating the head with the nail in those patients upon whom an open osteotomy was necessary. The head is very hard and dense. To drill and fix with the wood screws is more certain, although even here difficulty is frequently experienced in penetrating the hard epiphysis. The drill should be of the same caliber as the shank of the screw, and should penetrate to a depth equal to the length of the screw.

Postoperative care after blind nailing in the preslipped group or that with only mild displacement requires primarily the healing of the wound. Ambulation is instituted as soon as it is comfortable, but no weight-bearing is encouraged for three months.

The postoperative care in open reduction requires six weeks in the hospital. Russell traction is employed during this period, allowing early motion of the hip and knee. The patients are then ambulatory on crutches, with no weight-bearing on the hip which has been operated upon for a minimum period of three months. They are observed at three-month intervals for at least a year.

The criteria for judging the end results of these operative procedures are primarily the objective clinical findings as regards the function of the hip and the roentgenographic changes in the hip joint. The clinical end results are classified as excellent, good, fair, and poor. The goal to be attained for this condition is a normal hip, ascertained by the range of motion and function in the hip joint following the operative procedure. In this study the *excellent* hips are those in which the range of motion is essentially normal, except for a possible limitation in flexion or internal rotation, or both, of 5 to 10 degrees. Those classi-

TABLE I

CLINICAL RESULTS FOLLOWING THE OPERATIVE PROCEDURES

Operative Procedure	Results								
	Excellent		Good		Fair		Poor		Total
Wedge osteotomy and internal fixation	19	(56%)	3	(9%)	1	(3%)	11	(32%)	34
Open reduction without internal fixation	4	(36%)	2	(18%)	0		5	(46%)	11
Open reduction without wedge and with internal fixation	2	(50%)	1	(25%)	0		1	(25%)	4
Closed reduction with internal fixation	5	(83%)	0		0		1	(17%)	6
Internal fixation without attempted reduction	11	(69%)	1	(6%)	0		4	(25%)	16
Subtrochanteric osteotomy	2	(50%)	1	(25%)	0		1	(25%)	4
Totals	43	(57%)	8	(11%)	1	(1%)	23	(31%)	75

fied as *good* have flexion up to 90 degrees with no flexion contracture, and internal rotation beyond 10 degrees without pain. Those classified as *fair* have the same limitation of motion and mild restriction as the good hips, but have a minimum amount of pain or fatigue with activity. The *poor* end results are those in which there is limitation of motion of less than 90 degrees in flexion, a flexion contracture, and a "gluteal" gait; pain may or may not be present.

This lesion usually occurs between the ages of nine and seventeen years, with an average of thirteen years and five months. In this series, one patient had symptoms of two years' duration. Forty-eight of the patients (73 per cent.) were males, and eighteen (27 per cent.) were females. The obese appearance of these patients was noteworthy. Forty-six (70 per cent.) were obese, and only 20 (30 per cent.) had normal body weight.

The duration of symptoms in all cases of displacement of the upper femoral epiphysis was slightly over six months. In those cases in which the disability was caused by trauma, the duration ranged from four days to twenty-four months; in the cases of chronic slipping of the epiphysis, the range was from one and one-half months to eighteen months. An educational campaign for early recognition and treatment of this lesion is certainly indicated, and would be particularly valuable in this lesion with its limited age incidence, appearance of obesity, and characteristic clinical signs.

The duration of follow-up study in the cases reported here ranged from two months to twelve years, with an average of thirty-four months. In five cases in which the hip was operated upon, the period of follow-up was less than six months. Two of these patients are still under medical observation. The period of study of these cases extended from 1934 until December 1946. In response to a recent request, a number of these patients returned to the Clinic for check-up studies. Most of these had maintained the functional results observed a few months after operation.

The clinical results of the various operative procedures are shown in Table I.

Of the seventy-five hips * operated upon by all surgical procedures, forty-three (57 per cent.) had excellent clinical results; eight (11 per cent.) had good clinical results; one (1 per cent.) had a fair result; and twenty-three (31 per cent.) had poor results.

Of thirty-four patients in whom a wedge osteotomy with internal fixation was performed, nineteen (56 per cent.) had excellent clinical results; three (9 per cent.) had good clinical results; one (3 per cent.) had a fair result; and eleven (32 per cent.) had poor results.

* One hip of this series has been excluded, as our original operation was a Whitman reconstruction.

The results in eleven patients, in whom an open replacement of the head was performed without the use of internal fixation, showed that four (36 per cent.) had excellent clinical results; two (18 per cent.) had good clinical results; and five (46 per cent.) had poor results.

The open reduction without wedge and with internal fixation, carried out in four cases, resulted in two excellent results (50 per cent.), one good result (25 per cent.), and one poor result (25 per cent.).

In six patients in whom a closed reduction was obtained by means of traction or gentle manipulation and maintained by internal fixation, five (83 per cent.) had excellent clinical results and one (17 per cent.) had a poor clinical result.

Of sixteen patients in whom no attempt was made to correct minimum displacement, and internal fixation was used to prevent further deformity, eleven (69 per cent.) had excellent clinical results, one (6 per cent.) had a good clinical result, and four (25 per cent.) had poor clinical results.

Of four patients upon whom subtrochanteric osteotomy was performed, two had excellent clinical results and one had a poor clinical result. The poor result was undoubtedly due to the selection of an improper procedure. This patient had had marked limitation of motion in the hip joint before the operation had been performed.

The end results in thirty-eight hips treated by open reduction with internal fixation were as follows:

Excellent	21 (55 per cent.)
Good	4 (11 per cent.)
Fair	1 (3 per cent.)
Poor	12 (31 per cent.)

One of the patients with an excellent result has roentgenographic changes indicative of early aseptic necrosis. One patient with a good result has roentgenographic changes compatible with traumatic arthritis. In one of the patients with a poor result, non-union occurred at the osteotomy site. In the other eleven cases, the poor results were due to traumatic arthritis.

The successful results in 66 per cent. of the cases in this group would justify the procedure, if the delayed malum coxae senilis or degenerative arthritis were prevented from occurring later in life. The appearance of the hips seen ten or twelve years after

TABLE II

COMPARATIVE RANGES OF MOTION BEFORE AND AFTER OPERATION

Operative Procedures	Persistent *Normal* Range of Motion	Persistent *Equal* Limited Motion	Postoperative Motion		Total Cases
			Increased	Decreased	
Wedge osteotomy and internal fixation	1 (3%)	1 (3%)	23 (68%)	9 (26%)	34
Open reduction without internal fixation		1 (9%)	8 (73%)	2 (18%)	11
Open reduction without wedge and with internal fixation			4 (100%)		4
Closed reduction with internal fixation			5 (83%)	1 (17%)	6
Internal fixation without attempted reduction	7 (44%)	1 (6%)	4 (25%)	4 (25%)	16
Subtrochanteric osteotomy		2 (50%)	1 (25%)	1 (25%)	4
Totals	8 (11%)	5 (7%)	45 (60%)	17 (22%)	75

TABLE III

COMPLICATIONS REVEALED BY ROENTGENOGRAPHIC CHANGES CORRELATED WITH THE VARIOUS OPERATIVE PROCEDURES

Operation	Total No. of Hips Operated Upon	Complications			
		Degenerative Arthritis	Aseptic Necrosis	Non-Union of Epiphysis	Crushing of Neck
Wedge osteotomy with internal fixation	34	10 (29%)	1 (3%)	1 (3%)	0
Open reduction without internal fixation	11	3 (27%)	1 (9%)	0	1 (9%)
Open reduction without wedge and with internal fixation	4	2 (50%)	0	0	0
Closed reduction with internal fixation	6	0	1 (17%)	0	0
Internal fixation without attempted reduction	16	2 (13%)	0	0	0
Subtrochanteric osteotomy	4	1 (25%)	0	0	0
Whitman reconstruction	1*				
No operation	2	2**			
Totals	78 (100%)	18 (23%)	3 (4%)	1 (1%)	1 (1%)

* This patient had fibrous ankylosis of the hip.
** These patients had received no previous therapy, and are not included in the total of cases of degenerative arthritis as a complication.

operation makes us hopeful that a normal hip has resulted in these successful cases. Sufficient time has not elapsed, however, to be certain.

In the earlier cases, prior to the use of internal fixation, open reduction was performed on eleven hips (Table I). In the group with poor results, one head was displaced in plaster and an arthrodesis was performed subsequently; and one head and neck were crushed by a manipulation, prior to operation. External fixation without early mobility, and lack of secure fixation of the epiphysis, were responsible for the lower percentage of good results, in contrast to those obtained by open reduction with internal fixation.

Closed internal fixation without attempted correction of the deformity was carried out on sixteen hips (Table I). Those with preslipping and with mild displacement (less than one-third the diameter of the neck) fall into this group. It is surprising that this group had only a slightly higher percentage of successful results,—75 per cent. instead of 66 per cent.

TABLE IV

CORRELATION OF END RESULTS WITH DURATION OF SYMPTOMS *

End Result	Duration of Symptoms					Total Cases
	Not Stated	Less than 2 Weeks	2 Weeks to 3 Months	3 Months to 6 Months	More than 6 Months	
Excellent	4 (9%)	3 (7%)	9 (21%)	11 (26%)	16 (37%)	43
Good	1 (13%)	0	1 (13%)	1 (13%)	5 (62%)	8
Fair					1 (100%)	1
Poor	4 (15%)	0	8 (31%)	5 (19%)	9 (35%)	26

* Two patients, first seen with arthritic hips, had had no previous surgery.

in the thirty-eight cases treated by open reduction and internal fixation. Traumatic arthritis developed in two of the patients with poor results.

Excellent results were obtained with reduction by manipulation or traction, or both, and closed internal fixation, in five of six cases with acute traumatic displacement, in contrast to the chronic type with slow slipping.

Four hips were treated by subtrochanteric osteotomy. These cases were selected when malunion was incomplete, with obliteration of the epiphysis. External-rotation deformity in a movable hip gave an excellent result for the time being in these cases. Obviously, with the malposition of the epiphysis in this group, degenerative hip disease will eventually occur, even in those cases in which the present results are successful.

Even though the displacement of the upper femoral epiphysis is old or gradual in its occurrence, marked limitation of motion in the hip joint is frequently present. Although an increase in the range of motion does not satisfy the criteria given for the clinical classification, many of these cases show an increasing range of motion following the operative procedure (Table II).

The results of the open operation without wedge and with internal fixation showed that four (100 per cent.) of these patients had an increase in their range of motion after operation.

The patients with acute traumatic displacement of the epiphysis usually had marked limitation of motion before operation, as a result of the pain and muscle spasm, due to the trauma. In those in whom reduction was obtained by traction or gentle manipulation, five (83 per cent.) had an increase in their range of motion after operation; and one patient (17 per cent.), in whom aseptic necrosis developed, had a decrease in the postoperative range of motion.

Interestingly enough, of the patients upon whom internal fixation was performed without any attempt at reduction, four (25 per cent.) had a postoperative increase in their range of motion. Traumatic arthritis following the operative procedure developed in two of these cases, with decreasing range of motion. In seven (44 per cent.) of these cases a normal range of motion persisted, both before and after operation, and one patient had a persistent, equal, limited range of motion both before and after the operation.

Of the four patients upon whom subtrochanteric osteotomy was performed, two had a persistent, equal, limited range of motion both before and after operation. One had a postoperative increase in his range of motion, and one had a postoperative decrease in the range of motion.

Of all the operations performed—that is, in seventy-five hips—the normal range of motion persisted in eight (11 per cent.) both before and after operation. Five (7 per cent.) had a persistent, equal, limited range of motion before and after operation. Forty-five (60 per cent.) had a postoperative increase in their range of motion, and seventeen (22 per cent.) had a decrease in their postoperative range of motion.

The complications resulting from various operative procedures were four in number,—traumatic arthritis, failure of union at the osteotomy site, aseptic necrosis of the head of the femur, and a crushing injury to the head and neck resulting from a manipulative procedure (Table III).

The roentgenographic changes considered as indicative of traumatic arthritis are those in which there is a gradual or rapid loss of joint space; a generalized osteoporosis early in the postoperative period, and a subsequent loss of the subchondral bone; proliferative changes around the joint with deformity of the head of the femur and the acetabulum; and osteosclerosis of the articulating portions of the acetabulum and femoral head, with cystic degeneration. In certain cases it was difficult to state definitely whether all of the pathological changes demonstrated by roentgenogram were the result of traumatic arthritis alone, or whether they may have resulted from an associated aseptic necrosis, without serial roentgenographic evidence to substantiate its existence.

Aseptic necrosis is defined as a relative increase in the density of the femoral head with subsequent fragmentation and loss of substance, without early concomitant changes in the acetabulum and usually with a well-maintained joint space.

In eighteen of the seventy-five hips operated upon, traumatic arthritis developed. Obviously the greater proportion occurred in the group which had had open reduction; in approximately one third of these cases arthritis developed, whereas arthritis occurred in only 8 per cent. of the cases of internal fixation done blindly. The value of early recognition and early treatment is emphasized here. In spite of roentgenographic evidence of arthritis, two patients had good clinical results.

Two other cases have been added to this group, although the patients had received no previous therapy; arthritis developed and the patients consulted us primarily for the painful, stiff hip. They have been included in this study to demonstrate the spontaneous tendency for arthritis to develop, without treatment. Vitallium-cup arthroplasties were performed upon these two patients.

Aseptic necrosis developed in three of the cases. One patient has to date a full range of asymptomatic motion, but it is only six months since the operation. The area of aseptic necrosis seems to be localized at the superior margin of the head. In the reported case of aseptic necrosis following closed reduction with internal fixation, the head appeared dead prior to the nailing. Union occurred, however, and later a typical aseptic necrosis resulted. The authors feel that three of seventy-five hips operated upon (4 per cent.) do not constitute a high incidence of aseptic necrosis for operative procedures which can correct an otherwise certain disability.

Non-union of the epiphysis and the neck at the osteotomy site occurred in only one case. This was the result of inadequate fixation with a Smith-Petersen nail which was too short. It is a tribute to the procedure that failure to unite occurred only once.

The crushing of the head and neck of the femur is a complication which should not have occurred. Overzealous manipulation with the application of any force should not be employed in this group. This is a preventable complication.

The end results, both clinically and by roentgenogram, of the operative procedures in the twelve patients with bilateral hip involvement were essentially the same in both hips, even though a different procedure was done in each hip. Both hips did well or both did poorly in each case.

Table IV presents a correlation of the end results with the duration of symptoms. In our Clinic, the acute injuries are in a minority, so that the table is not of much value, except to point out that good or excellent results could be obtained some months after the onset of the lesion. The acute traumatic displacements, readily reduced and fixed internally by blind nailing, did produce the best results.

It has been observed in several patients in whom traumatic arthritis developed that, in serial roentgenograms, the joint space previously lost was re-established. This restoration of an essentially normal joint space was accompanied by relatively little improvement of the functional result. An explanation for this phenomenon is lacking, but possibly it results from a loss of the superficial layers of articular cartilage, with a retention of the germinal layer. With later proliferation of the germinal layer, the joint space is re-established.

CONCLUSIONS

With careful selection of cases and the proper operative approach, the authors feel that open operative correction by transcervical osteotomy and internal fixation gives the best chances for good function of the hip joint. In the slipped upper femoral epiphysis with malunion, because of the re-establishment of a normal anatomical relationship, the chance of this good function persisting into later life is excellent. Sixty-eight per cent. of the hips operated upon by this method had good hip-joint function, some having been observed as

long as twelve years after the operation. We feel that this percentage justifies our continuance of this operative procedure.

Blind fixation of the epiphyseal line in the preslipped and early phases of slipping insures against the possibility of subsequent, more extensive, displacement. Such a procedure does not predispose the hip to the development of arthritis.

The two major complications arising as a result of the operations on the hip for this condition are traumatic arthritis and aseptic necrosis. Only 4 per cent. of the hips which were operated upon revealed roentgenographic evidence of aseptic necrosis; consequently it is not a frequent complication of the operation. Definite evidence of traumatic arthritis was present in 24 per cent. As this developed in two patients in whom no therapy had been attempted and in two in whom blind nailing had been performed, it has led the authors to conclude that the operative procedure is not the only factor contributing to this complication, but that some intrinsic predisposition toward this complication exists in this peculiar condition.

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DISCUSSION

DR. LEWIS CLARK WAGNER, NEW YORK, N. Y.: I should like to bring out a few points concerning these papers.

1. Early diagnosis probably would preclude all this discussion. I agree that in cases in which the diagnosis is suspected or arrived at early, where there is no slipping or a minimum of slipping of the epiphysis, a well-placed nail, transfixing the neck and the head on the affected side, would yield a cure in almost every case. It is important that there be no weight-bearing for at least six months in these cases, as the nail serves only to prevent further slipping until union of the epiphysis can progress in the usual manner.

2. Closed reduction should be attempted only in the acute traumatic case. I have often attempted to reduce the slipped femoral epiphysis under direct vision with the hip joint opened, and I have concluded that it cannot be reduced. One is apt to be deceived because, when the limb is internally rotated and abducted, it gives the appearance of reduction with lengthening of the neck. However, in the lateral roentgenogram, we find that no change has taken place.

3. When the narrowed joint space is noted in the old cases and degenerative changes are present in the articulation, nothing can be done except to hope for the best or to perform an arthrodesis of the hip. Arthroplasty may be tried, but I am reserving my opinion on that.

4. Subtrochanteric osteotomy, I feel, is the second choice for the treatment of badly slipped epiphyses. In patients with marked limitation of motion and the limb in external rotation, with or without flexion deformity, the surgeon, whose care is sought from three to five years after the initial symptoms, can hope only to salvage what is left and to let Nature take its course, after the deformity of the femur has been corrected and the limb has been placed in the attitude of good function, which is correction of the external rotation and the flexion-adduction deformity. Subtrochanteric osteotomy is probably best suited to the average surgeon.

5. I consider the wedge osteotomy of the neck of the femur the operation of choice. This operation should be limited to patients from eleven to fifteen years of age, whose slipping has been present from a few months to a year or over. It is most satisfactory when there has been up to 70 per cent. slipping of the head on the neck. We have had most gratifying results in over twenty cases in the last ten years. I am sure many surgeons have tried the wedge osteotomy, but have abandoned it because they did not follow through the treatment correctly. There are many technical difficulties.

This treatment seems to be most rational because, in these advanced cases, we see an apparent disruption of the circulation of the head of the femur,—circulation which, at its best, is inadequate. At this stage, union apparently has begun to take place with the hip in the deformed attitude, in an attempt at normal restoration of circulation. To try to replace the head of the femur by division of the epiphyseal line would add trauma to the already impaired circulation of the head. The neck of the femur has ample circulation so that, by removal of a section of bone through the cancellous area, the circulation of the impaired epiphyseal

plate is not disrupted. By this method, we have restored the anatomical position of the head of the femur, corrected the coxa vara, and given Nature the best chance to aid in the healing of the affected parts.

I am not unmindful of the pitfalls and hazards that may arise, should not extreme care, gentleness, and diligent attention to detail be followed in this form of treatment.

DR. HAROLD E. CROWE, LOS ANGELES, CALIFORNIA: Since I have come to accept as gospel the work of Dr. Eugene Wolcott on the blood supply of the capital femoral epiphysis, I do not do osteotomies through the neck of the femur. If the gentlemen who have presented operations today are able to do so without injury to the periosteum, great credit is due them as surgeons. Until I feel able to do this surgery more easily, I do not plan to undertake this type of operation.

We must have large numbers of statistical facts, and Dr. Badgley has given us these facts. Undoubtedly in a large scientific institution it is all right to have 32 per cent. of bad results, but in the town in which you practise, one case of aseptic necrosis would be a major catastrophe. I have not had the opportunity to see the roentgenograms of Dr. Martin's cases, but I have looked over Dr. Badgley's roentgenograms, as displayed in his scientific exhibit at this meeting. I found only one hip in which I felt a true normal had been restored. All of the hips presented in these roentgenograms will undergo major degenerative changes within twenty years.

While it is wonderful to have given a sixteen-year-old boy twenty years of useful hip function, at age thirty-six, when the man has reached the high point of productive activity, a degeneration of the hip with pain sufficient to stop his activities will be a major catastrophe. None of us can follow a thousand individuals with this type of illness through a twenty-year period, since none of us can live that long. It must be the accumulated effort of many men to produce a series of one thousand cases with a twenty-year follow-up; and, until that has been done, I feel that most of us should use the procedure given by Dr. Vernon P. Thompson in 1937, and published in 1943 as the V-shaped telescoping osteotomy (*Archives of Surgery*, **46**: 772, 1943). He produced excellent hips, without signs of such degeneration as we have seen in the exhibit.

DR. ALAN DEFOREST SMITH, NEW YORK, N. Y.: I would like to correct the statement which Dr. Badgley made about the practice at the New York Orthopaedic Hospital in regard to open reduction of the slipped epiphysis. It is true that we made the statement several years ago that we did not approve of this operation. We have found, however, that it is necessary to do an open reduction by an osteotomy through the neck of the femur in severe cases, but we confine the operation to the most extreme deformities. In the less severe displacements, we still prefer to correct the internal rotation and adduction by a subtrochanteric osteotomy. Fortunately, most of our cases are seen in the early stages, when correction of the deformity is not necessary.

The operation which we have used for some time to effect an early closure of the epiphyseal line is to expose the neck of the femur and to cut a small window, about one centimeter square, in the neck, close to the margin of the head. Through this a drill is passed across the epiphyseal line into the head in several directions, and a small sliver of bone is placed in each drill hole. This produces bony union between the head and neck in an average of about eight weeks, at which time it is possible to get the patient up with crutches. We do not immobilize the hip after the operation.

DR. J. ALBERT KEY, ST. LOUIS, MISSOURI: In 1922, I reviewed all the cases of slipped epiphyses we had had at the Massachusetts General Hospital. At that time we showed this as a migration of the epiphysis. It happens during a period of rapid growth. This "new" operation that is being reported has been done all over the country for twenty years. When Smith-Petersen introduced his nail, that was used. You can only reduce the displacement by shortening the neck. The head is found on the posterior portion of the neck and is united by bone. When you get enough bone out to permit reduction, you usually find a ridge of bone on the posterior and inferior borders of the neck, and this must be removed.

I had two cases of aseptic necrosis before the Smith-Petersen nail was introduced. I have had no case since, but have had one case of ankylosis. I have not done so many operations as Carl Badgley and his associates, but most of the results have been good hips. They are going to be good hips at sixty-five. If you do a subtrochanteric osteotomy and do not correct the position of the head, an arthritis will be produced by incongruity and not by nutritional changes. This may occur as a result of an operation done twenty years previously. Some of these are so markedly rotated externally that I have pulled off the greater trochanter, trying to reduce the displacement.

This is the operation of choice in my hands. You will not get aseptic necrosis in enough cases to make it worth while to do any other procedure with which I am familiar. I believe you will get permanently good hips, if you do the operation fairly well.

DR. WILLIAM T. GREEN, BOSTON, MASSACHUSETTS: I would like first to comment on Dr. Martin's paper. At the meeting of the American Medical Association in Cleveland in 1944, we described in detail a technique which has little variation from that described by Dr. Martin. I would like to emphasize one or two points. One is that there is what amounts to a mesentery on the inferior aspect of the neck of the femur—

the retinaculum of Weitbrecht—which contains a large part of the vascular supply for the head of the femur. In slipped epiphysis, as the neck migrates forward and upward, the superior cervical vessels are interrupted and the inferior cervical vessels of the retinaculum are shortened, but maintain their continuity. If the vessels remain in this shortened position for any length of time, they adapt themselves to this new length. However, if the head is pried into position, they must necessarily be stretched beyond their adaptive length, occluding their lumina, which may well precipitate aseptic necrosis of the head. The problem, then, is a little more than removing enough bone to restore alignment and to be able to pry on the head. One must remove enough bone from the neck to place the head in position without tension on the inferior vessels. A careful subperiosteal dissection for exposure of the neck is important, but in this the big thing is to preserve the inferior vessels.

I would like to call attention to the results obtained in a group of cases which were treated by traction to the extremity in internal rotation, followed by a hip spica, which in turn was followed by counterpoised traction with motion; this was called the traction-spica-traction method. These cases were reported in the paper referred to, which was published in the *Archives of Surgery* in January 1945 (vol. 50, pp. 19–32). The indications for the use of this method were outlined, and the results obtained were as good as those in any group with which we are acquainted.

Dr. Paul H. Martin (closing): In my paper I was mainly attempting to make two points. The first concerns the dangers of manipulation. I think most of us have at some time been intrigued with that form of intervention; but it is too dangerous, even if unsuccessful. Also, many of the poor results which follow open reduction may be due to the trauma of a preliminary attempt at reduction by manipulation. Therefore, if we cannot get a large series of cases to study which have had no preliminary manipulation, I do not see how we can get any accurate idea of the results of operative reduction.

Dr. Key has said that open reduction is nothing new and has been done all over the country for twenty years. Yes, open reduction has been done all over the country, probably by most of you, during the last twenty years. But how? And with what results? Too many cases of aseptic necrosis, too much traumatic arthritis, too many poor results. Something has been lacking in the method, or rather in the technique.

The second point I tried to establish in my paper was the extreme importance of preserving the essential attachments of the epiphysis at operation. From the picture Dr. Wagner showed, it was not clear to me that he was talking about the same thing I was talking about. In the slides he used to illustrate his discussion, the periosteum had not been reflected and preserved in the way which we think is essential to avoid injury to the blood supply. Nor was this evident in the slide which Dr. Badgley showed. When we come to appreciate the importance of the periosteal blood supply of the epiphysis, I am sure that the results of open reduction will improve.

I wish to thank the gentlemen who discussed our papers.

SUMMARY OF RESULTS OF BONE-GRAFTING FOR WAR INJURIES

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The purpose of this paper is to record the experience obtained in the transplantation of autogenous bone for the treatment of 156 consecutive cases of fracture of the long bones with non-union or limited union, sustained as a result of war injuries. The patients in this series were treated in the Section of Orthopaedic Surgery of Deshon General Hospital, Butler, Pennsylvania, during the years 1943 to 1946. The facilities for treatment were those of the average named Army General Hospital in the Zone of the Interior, and were of outstandingly high quality in all respects. The clinical work was performed by several fully qualified orthopaedic surgeons, and the results are to be viewed as those of group effort.

These patients were received at Deshon General Hospital from six weeks to several months after the initial injury overseas and, with the exception of eighteen patients who were operated upon within a few months of the closing of the Hospital in the spring of 1946, they remained for the entire period of definitive treatment, thus permitting an evaluation of the end results. Compound fractures had occurred in 80 per cent. of the cases, and almost all were solely injuries of the bones and soft tissues, not accompanied by peripheral-nerve or vascular injury.

An estimated 8,000 fractures of the long bones were treated at this Hospital during its period of activity, and the incidence of non-union and limited union can thus be estimated roughly as about 2 per cent.

The diagnosis of non-union was made by conventional criteria. In many cases, with loss of bone substance and a gap between the fragments, the diagnosis was obvious. When an acceptable reduction of the fracture existed, the presence of false motion at the fracture site at the end of six months, plus roentgenographic evidence of failure of union, was considered to indicate non-union. However, it was found that the arbitrary six-month period could often be revised downward for fractures of the tibia, where non-union might be strongly suspected at four and one-half or five months; and very frequently it could be revised upward for fractures of the femur, which often united at eight or nine months by closed methods.

The timing of operative intervention, in a large number of cases, was dependent upon the complete healing of soft-tissue wounds and the restoration of skin, adequate in quality and quantity, at the level of the fracture site. In instances of soft-tissue deficiency in the area of approach to the bone-graft operation, the appropriate soft-tissue plastic procedures were carried out meticulously, preliminary to bone surgery. The misfortunes attending disregard of this fundamental rule were observed in a few instances early in the series.

No postoperative infection at the site of the donor bone occurred. Postoperative fracture of the donor tibia occurred in four instances, and the application of a tibial caliper brace was employed frequently in the latter part of the series to prevent this complication.

All patients received penicillin postoperatively for two weeks, or longer when indicated.

RESULTS

A total of 156 cases were treated by autogenous bone-grafting,—in 137 instances for non-union, and in 19 instances for limited union.

Of the 137 cases of non-union, the end results are known in 119. Of these, the procedure was successful in securing union in 104 cases (87.4 per cent.). The procedure failed in fifteen cases (12.6 per cent.). Eighteen cases were lost track of before the end results could be judged.

TABLE I

RESULTS OF BONE GRAFTS FOR NON-UNION IN ENTIRE SERIES

Location of Graft	No. of Grafts	End Results Known	Successful Results		Failures	
			No.	Per cent.	No.	Per cent.
Humerus	13	10	9	90	1	10
Radius	13	8	6	75	2	25
Ulna	21	17	15	88.2	2	11.8
Metacarpals	27	27	27	100	0	0
Femoral neck	5	4	4	100	0	0
Femur	13	10	7	70	3	30
Tibia	38	36	29	80.6	7	19.4
Medial malleolus	7	7	7	100	0	0
Totals	137	119	104	87.4	15	12.6

Of the fifteen failures, eight were complicated by postoperative infection, and in seven the wounds were clean postoperatively. A total of eighteen postoperative infections occurred in the entire series (11.5 per cent.).

The results for the complete series are summarized in Table I.

The inclusion of non-union of the metacarpals and medial malleoli, for the sake of completeness in a consecutive series, gives a percentage of successful cases which is weighted unduly by non-unions that respond readily to bone-grafting and offer relatively little technical difficulty. Table II summarizes the results when the metacarpals and medial malleoli have been excluded, and gives a truer picture of the findings in the more difficult types of cases. In this smaller group, comprising non-union of the humerus, radius, ulna, femoral neck, femur, and tibia, the end results are known in eighty-five cases, of which seventy (82.4 per cent.) were successful and fifteen (17.6 per cent.) were failures.

FINDINGS IN INDIVIDUAL GROUPS

Humerus

Thirteen cases of non-union of the humerus were treated. The end results could be determined in ten, of which nine (90 per cent.) were successful and one (10 per cent.) was a failure.

There was a high incidence of gross comminution and loss of bone substance in this group; and, in all of the thirteen cases, the fracture site was near one end of the bone, seven being in the proximal fourth and six in the distal fourth. They commonly presented an especially difficult technical problem in the anchoring of the graft to the short fragment, which often was not long enough to permit the use of an onlay graft. This difficulty was

TABLE II

RESULTS OF BONE GRAFTS FOR NON-UNION, EXCLUDING METACARPALS AND MEDIAL MALLEOLI

Location of Graft	No. of Grafts	End Results Known	Successful Results		Failures	
			No.	Per cent.	No.	Per cent.
Humerus	13	10	9	90	1	10
Radius	13	8	6	75	2	25
Ulna	21	17	15	88.2	2	11.8
Femoral neck	5	4	4	100	0	0
Femur	13	10	7	70	3	30
Tibia	38	36	29	80.6	7	19.4
Totals	103	85	70	82.4	15	17.6

usually overcome, in the proximal fourth, by impounding a tibial graft into the head and neck, and onlaying the distal portion of the graft to the shaft with metal-screw fixation. Any existing gap was closed by shortening. In the distal fourth, an intramedullary peg of tibial cortex was used in three cases. The undesirable features of intramedullary grafts in general were fully appreciated, but it was felt that the firm fixation afforded by this type of graft in this location offset its disadvantages. In the remaining three cases in the distal fourth, it was possible to use onlay grafts.

The one failure was in a fracture of the proximal fourth, and was secondary to postoperative infection.

Radius

Thirteen cases of non-union of the radius were treated. The end results could be determined in eight, of which six (75 per cent.) were successful and two (25 per cent.) were failures. The usual procedure was a tibial onlay graft with metal-screw fixation.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Patient has sustained compound fracture from gunshot, with median-nerve paralysis. Bone-grafting was done six months after drainage of wound had ceased.

Fig. 1-B: Roentgenogram taken during interval study after grafting. Successful union was obtained subsequently, with 50 per cent. rotation of the forearm and spontaneous recovery of the median nerve.

FIG. 2-A

FIG. 2-B

Fig. 2-A: Patient had compound fractures of femur, tibia, and radius. Successful secondary closure of all wounds was carried out overseas two weeks after injury. All fractures united, but the femur had limited union. Refracture of femur occurred while patient was in ischial caliper brace. Traction and suspension were resumed, and limited union was obtained.

Fig. 2-B: Roentgenogram taken after bone-grafting. Knee motion was from 180 to 85 degrees.

Of the two failures, one was due to an immediate gross postoperative infection, necessitating the eventual removal of the graft. The second was probably due to faulty technique. Another grafting procedure was done subsequently, the result of which is not known.

Ulna

Twenty-one cases of non-union of the ulna were treated. The end results could be determined in seventeen cases, of which fifteen (88.2 per cent.) were successful and two (11.8 per cent.) were failures.

These fractures commonly presented gross loss of bone substance, with resulting bone gaps up to two inches. The ease of exposure, however, rendered them technically simple to deal with. A tibial onlay graft was used most frequently, a tibial inlay graft was used in a few cases, and a sliding onlay graft was employed in one instance. Metal-screw fixation was preferred, but poor quality and caliber of bone occasionally prevented its use, and loops of stainless-steel wire had to be resorted to. Wire had the disadvantage of offering less security, and tended to be irritating afterward in its subcutaneous location. Wire was the method of fixation in one of the failures.

The two failures occurred in the same patient. A large bone defect was bridged with a tibial onlay graft, which failed to unite with the proximal fragment. The failure was probably due to the inability of the operator to deal effectively with a proximal fragment of bone of poor quality. A second attempt failed in the same area. A third procedure was carried out, the end result of which is not known.

Metacarpals

Twenty-seven cases of non-union of a metacarpal were treated routinely by the inser-

tion of an intramedullary dowel of tibial cortex. Union was obtained in every case. A mild transient infection occurred in one case, but it did not interfere with the final result.

Femoral Neck

Five cases of non-union of the neck of the femur were treated. The end results could be determined in four, all of which were successful.

The method of treatment employed was the placing of a bone dowel through the femoral neck, across the fracture site. The hip was opened in one case, the fracture site was visualized, the fracture was reduced, and a portion of the fibula was driven through a drill hole under direct vision. In another case, two small grafts of tibial cortex were placed blindly. Postoperative roentgenograms showed one graft to be too short to cross the fracture site, but union was obtained after considerable delay. In the remaining two cases, a dowel of tibial cortex, one-half inch in diameter, was placed blindly through the neck.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Compound fracture resulted from gunshot. Successful skin-grafting was performed overseas; bone-grafting was done four months after completion of the skin graft.

Fig. 3-B: Roentgenograms taken during interval study after bone-grafting. Low-grade infection of wound supervened. Devitalized bone and part of the metal were removed six months after grafting. The remaining metal was removed nine months after bone-grafting. Complete wound healing and successful union had occurred eleven months after grafting.

TABLE III

PRESENCE OF INFECTION AFTER BONE-GRAFTING

Location of Graft	No. of Patients Operated Upon	Postoperative Infections Within Group		Failure of Procedure Caused by Post-operative Infection
		No.	Per cent.	
Humerus	14	2	14.3	1
Radius	13	1	7.7	1
Ulna	21	2	9.5	0
Metacarpal	27	1	3.7	0
Femoral neck	5	1	20	0
Femur	21	2	9.5	2
Tibia	48	9	18.8	4
Medial malleolus	7	0	0	0
Totals	156	18	11.5	8

Femur

Thirteen cases of non-union of the femur were treated. The end results could be determined in ten cases, of which seven (70 per cent.) were successful and three (30 per cent.) were failures. A single tibial onlay graft with metal-screw fixation was the method usually employed. Two of the failures were due to postoperative infection. The third failure was in a femur of extremely poor vitality. There was no evidence of bone regeneration after grafting, and the graft finally broke. A double onlay graft would probably have produced a better result.

It is believed that the small number of femora which came to operation is a reflection of the conservative handling of this fracture. In many instances, an apparent failure of union at six months was converted into union at eight or nine months by continued traction and suspension. It is felt that, by using the intervening time to promote knee action, these patients were made ambulatory, with a solid femur and an adequate range of knee motion, earlier than if they had been subjected to a bone-grafting procedure at the end of six months.

Tibia

Thirty-eight cases of non-union of the tibia were treated. The end results could be determined in thirty-six cases, of which twenty-nine (80.6 per cent.) were successful and seven (19.4 per cent.) were failures.

A variety of methods were necessary to deal with the complex fracture patterns encountered. The most common type was an inlay graft from the opposite tibia, applied to the medial surface. It was desirable to fix the graft so securely by mortising that metal-screw fixation was unnecessary, and among the benefits of this method was a considerable saving of operating time. However, metal-screw fixation had to be used in many instances. The graft was applied to the lateral surface of the tibia in several cases early in the series; this area was abandoned subsequently in favor of the medial surface, because of the ease of approach. Sliding inlay grafts were used when the fracture site was conveniently located in the proximal or distal portion. Combinations of onlay and inlay grafts, plus the use of bone chips, were devised to bridge the grossly comminuted fractures with loss of bone substance. The ingenuity of the operator was sometimes taxed severely to accomplish both fixation and restoration of continuity in these grossly shattered tibiae. Osteotomy of the fibula sometimes permitted a better approximation of the tibial surfaces, by allowing shortening to close a small persistent gap. The supportive effect of an intact fibula, however, was not to be dispensed with lightly. A combination of inlay and intramedullary graft was used successfully to bridge a gap in one instance.

TABLE IV

RESULTS IN SIXTEEN CASES OF FRANK OSTEOMYELITIS AND NINE CASES OF LONG-CONTINUED DRAINAGE, AFTER BONE-GRAFTING

Results	Osteomyelitis		Long-Continued Drainage	
	Without Postoperative Infection	With Postoperative Infection	Without Postoperative Infection	With Postoperative Infection
Union obtained	3	4	6	1
Procedure unsuccessful	1	2		1
End result not known	6		1	
Totals	10	6	7	2

The procedure failed in seven instances:

In one case there had been drainage from the site of fracture for eight months after injury. Bone-grafting was performed 1.4 months after the establishment of a dry wound. A gross postoperative infection followed, with disruption of the graft.

An osteomyelitis had followed injury in the second case, with gross loss of soft tissue in the region of the fracture site. The osteomyelitis responded to conservative treatment, and the soft-tissue defect was covered successfully by a pedicle skin graft, nine months after injury. Bone-grafting for non-union was performed 1.8 months after the completion of the skin graft. Eight weeks after bone-grafting, a slight amount of drainage from the wound was present, and a slow, progressive breakdown of the wound ensued. Multiple sequestrectomies of the host bone were performed, but in spite of the active infection present, the graft remained firmly in place, appeared to be uniting, and was allowed to remain. The outcome in this case is not known.

In the third case, bone-grafting was performed 5.8 months after a successful skin graft. An immediate gross postoperative infection followed the bone-grafting.

In the fourth case the removal of a protruding bone fragment at another hospital was required, three months after injury. Drainage ceased two months later. A small area of scar was excised; fresh skin edges were approximated; and healing was obtained. Bone-grafting was performed 0.6 month after healing of the skin wound. Slight drainage from the wound was noted two weeks after operation, but this gradually ceased as a result of penicillin therapy. In a period of nine months after operation the fracture became firmly united, but a low-grade osteomyelitis continued and several sequestrectomies, in areas relatively remote from the graft, were performed. It is felt that the osteomyelitis was influenced adversely by a poorly timed operation, and the case is classed as a failure.

Osteomyelitis was present for eighteen months after injury in the fifth case, necessitating two sequestrectomies at other hospitals. The bone-graft procedure had been done

TABLE V

RELATION OF POSTOPERATIVE INFECTION TO WAITING PERIOD IN SAMPLE GROUP OF SEVENTY-TWO CASES

	Length of Waiting Period			Total
	One to Three Months	Three to Six Months	Six to Eight Months	
Without postoperative infection	9	31	18	
With postoperative infection	6 (40%)	8 (20.5%)	0	
Totals	15	39	18	72

through a tense, poorly nourished, scarred skin area, which broke down after operation and exposed the area of grafting. It is felt that the failure to provide adequate soft-tissue covering was the dominant error in this instance.

The sixth was a clean case, and failure of union was probably due to poor technique.

A history of fracture of the tibia in infancy, possibly at birth, was obtained in the seventh case. Union, with a marked lateral bowing deformity, was obtained, apparently after the passage of considerable time. Spontaneous fracture of the same tibia occurred during a forced march in Africa. Bone-grafting was performed, without correction of the bowing deformity, and failure resulted. A second bone graft, with correction of the deformity by osteotomy, was successful.

Medial Malleolus

Seven cases of non-union of the medial malleolus were treated, and union was secured in all. Each was treated by the insertion of a dowel of tibial cortex across the fracture site. In most instances, the fracture line could not be obliterated completely, and it was necessary to fill the space with bone chips.

LIMITED UNION

Limited union is defined as union occurring in fractures with loss of bone substance, in which the consolidation takes place in a relatively small area of the fracture site, as seen in cross section; the fracture is thus firm only across a strut. The possibility of the eventual deposition of sufficient amounts of additional effective bone was considered to be remote, and the likelihood of subsequent refracture was considered to be great.

The nineteen cases of limited union in this series included ten tibiae, eight femora, and one humerus.

The findings at operation almost invariably proved the need for operation in these cases. The bone defects were found to be filled with dense, adult-type fibrous tissue, in which the further laying-down of bone appeared to be highly unlikely. After excision of the scar tissue, the bone defect was seen to be much more extensive, as a general rule, than had appeared by roentgenographic study. Particularly in defects which were spiral in character, roentgenograms usually failed to demonstrate, in routine projections, the full extent of the deficiency.

The operative procedure involved complete excision of scar tissue from all the ramifications of the defect, freshening of the defect to raw bone, and filling it with bone chips from the ilium or with a tibial graft fashioned to fit snugly. In two instances, it was necessary to complete the fixation of a tibial graft with one metal screw.

There were no postoperative complications in this group, and in all cases, approximately normal bone caliber at the fracture site was restored.

INFECTION

A total of eighteen patients in the entire series of 156 cases suffered postoperative infection, of major or minor degree, following bone-grafting (Table III). Of these infections, nine were severe, causing failure of the procedure; six were moderate; and three were mild. Of the nine moderate and mild infections, the bone graft was successful in spite of the infection in seven cases, and the results are not known in two.

The gravity of this complication makes pertinent an inquiry into the background in these cases. Eighty per cent. of the patients in the entire series had originally had compound fractures, sustained in wartime in combat areas. Varying degrees of soft-tissue damage accompanied the bone injury, and the presence of bacterial contamination may be suspected. More specifically, sixteen patients showed frank osteomyelitis on admission; in these cases, sequestrectomy was performed at some time prior to bone-grafting. Nine patients had had long-continued drainage from the fracture site; in them, some degree of

osteomyelitis was to be suspected. Eight of the postoperative infections after bone-grafting occurred in this combined group of twenty-five cases. (Table IV shows the outcome in this group.)

There is considerable controversy as to the optimum time for bone-grafting in a case of non-union with previous infection. Before the sulfonamides and penicillin were available, a conservative attitude was conventional; and a considerable length of time, usually from six to twelve months, was allowed to elapse after the wound had healed before operation was undertaken. Under penicillin protection, there has been an appreciable tendency to shorten the waiting period, and what now constitutes a reasonable and safe waiting period is far from clear. In the present series, the waiting periods have ranged from one to eight months; and, in a portion of this series, it is possible to study and record the incidence of infection after bone-grafting in relation to the waiting period.

A sample group of seventy-two cases within the series lends itself to study; these were the only cases in which the record bore a notation of the exact date upon which a previously draining wound was considered to be dry and healed, thus permitting a precise computation of the waiting period. Within this sample group, the waiting periods ranged from one to eight months.

In Table V is recorded the incidence of postoperative infection in waiting periods of varying lengths. Fifteen patients were operated upon after intervals of from one to three months; the rate of postoperative infection was 40 per cent. in this group. Thirty-nine patients were operated upon after a wait of from three to six months; the rate of postoperative infection was 20.5 per cent. in this group. Eighteen patients were operated upon after intervals of from six to eight months, with no postoperative infections.

This series of cases is not large enough to justify definite conclusions as to the optimum waiting period which should precede bone-grafting in a case of non-union with previous infection. At the same time, it is suggested that it may be unwise to allow penicillin protection to replace unduly a waiting period of adequate length. The balance to be maintained between these two factors may well be the key to success in operations for this type of case. What may be considered an adequate waiting period in conjunction with penicillin coverage is not yet clearly established, and further studies of this nature will be needed.

INTERNAL CONTACT SPLINT *

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The internal fixation of fractures has a definite, but limited, field of application in the treatment of fragment displacement. The closed method of treatment of fractures has been accepted as the most desirable, with splint, casts, or controlled traction to maintain the reduction. However, a certain number of fractures present problems, in the solution of which operative reduction and direct fixation of the fragments offer reasonable help.

Improvement in operative technique and a better appreciation of the physiological reaction of the low-metabolic processes of bone permit a reasonable understanding of surgical fracture repair. The introduction of metals with decreased chemical or electrolytic reaction has improved the use of foreign material in the surgical treatment of fractures.

The clinical and microscopic observations of fracture ends of fragments of bone have shown variable absorption of the fracture surface. The inactive area of devitalized bone is absorbed, which permits the viable bone of each fragment end to come into contact when proper reduction has been carried out. The contact is accomplished by the longitudinal muscle thrust in closed reductions. When direct contact of the fragments is prevented by any mechanical device, union of the fracture may be delayed or non-union may result. The clinical observation of a fractured tibia with an intact fibula has been an experience of many in cases of delayed union or non-union. Another observation has been the appearance of the line of absorption between the fracture ends of the fragments of bone, held in position by the usual type of commercial plate. The immobilization is complete, and the plate actually keeps the fragment ends apart by a distance equivalent to the absorbed portion (Fig. 1). The result may be delayed union or non-union, and often the plate will bend or break (Fig. 2). By examining the fracture site, we can see bony union attempted or accomplished by those portions of the fragment ends actually in contact.

In an effort to eliminate this factor of non-contact in many fractures on which plates have been used, and to reproduce the contact of the fragment ends as observed in closed reduction, the slotted type of plate was designed (Fig. 3). The plate is not applied to the fragment ends, as is the usual metal plate. Four screws are used in the slotted plate; the screws are applied as far distant from the fragment ends as possible and thus do not contribute additional trauma to the damaged area. In addition, the gliding slotted plate is not completely immobilized, nor is it loose. Actually, it permits controlled longitudinal motion when the screws are not set tightly. Thus, the muscle tone which produces a longitudinal thrust on the bones is permitted to function and to maintain the fragment ends in constant contact during the recovery period. In this manner, the fragments are allowed to maintain the mechanical and physiological apposition which is conducive to bony union (Fig. 4).

Application of the slotted plate, which the author prefers to call the internal contact splint to emphasize the fact that it is not applied firmly to the bone, is technically not so difficult as plate immobilization. The surgeon does not have to apply oblique fixation screws across the fragment ends of the bone or to struggle for perfect contact before placing screws in both fragments. The splint is placed in the fractured area along the longitudinal axis of the shaft and the four screws are inserted, two on each side of the fracture site, with a space between the screws and ends of the slot. The fragment ends can then be placed in close contact. When anaesthesia ceases, the tone returns to the muscle, and the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1947.

FIG. 1

Absorption of the fragment ends, twelve weeks after operative reduction.

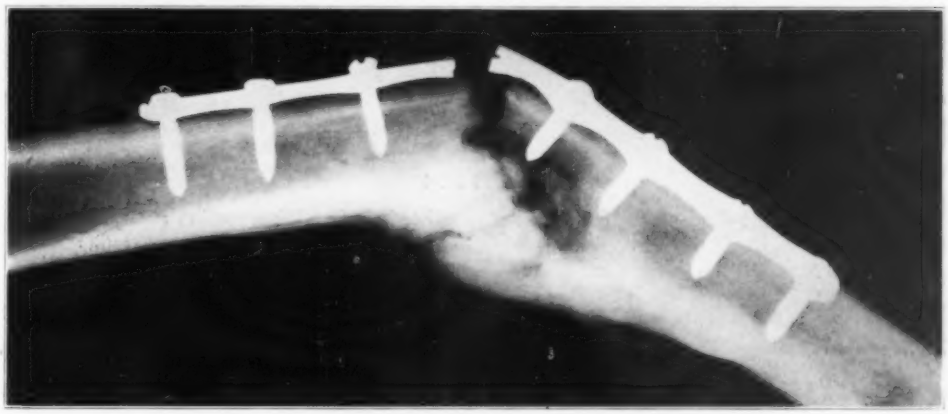

FIG. 2

Plate has broken. Note pressure atrophy of cortex due to tight plate, lack of osseous activity adjacent to the plate, and attempted union where contact of bones is present. Screws were short, but provided sufficient security.

longitudinal forces cause the ends to remain in constant contact during the healing period. If absorption of the fragment ends takes place, the deficiency is automatically obliterated, as in the closed reduction, and a mechanical and physiological situation favorable for union is created (Figs. 5-A to 5-H, inclusive).

The contact splint is useful in fracture of the shaft of a bone in an adult.

The care after open reduction is supportive, as would be required in the same fracture by the closed method. Earlier mobilization of joints is practised, and muscle activity in the fracture area is initiated during the first week after operation.

The extensive metal fixation of fractured bones is not physiological, and splinting is only a means to normal restoration of function. Supportive metal is not a substitute for the normal physiological repair of bone.

Some of the advantages of the contact splint are listed:

1. The fragment ends are easily placed together in exact approximation; the muscle pull will maintain the desired contact. Placing the screws in the bone is, therefore, easier.

2. Oblique fixation screws across the fractured ends are eliminated;

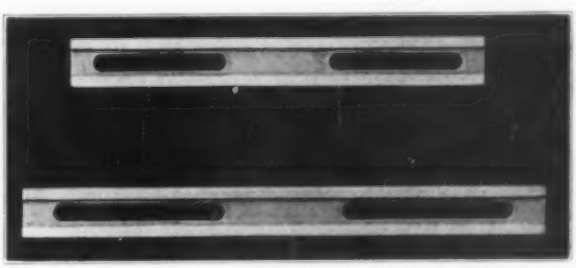

FIG. 3

Four-inch and five-inch splints. Six-inch and three-inch sizes (one slot and two slots) are also used.

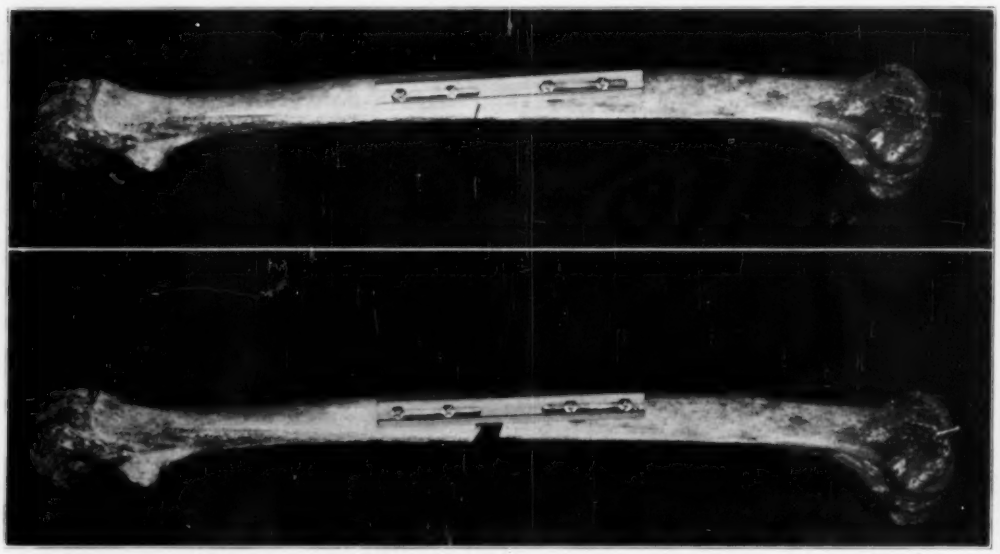

FIG. 4

Splint applied, showing longitudinal motion permitted. This gliding motion must be permitted to continue throughout the entire period of recovery. The screws should not be tightened.

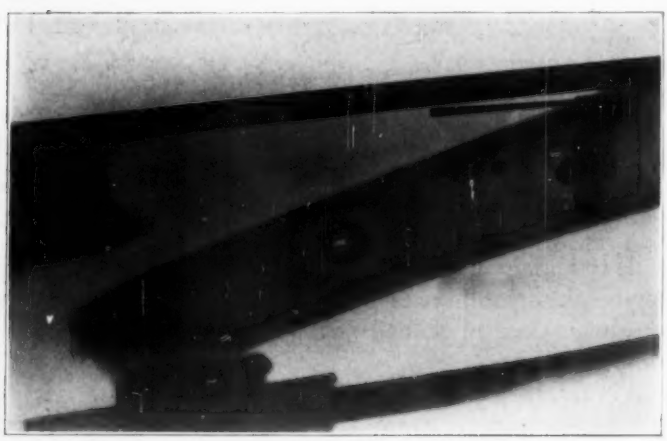

FIG. 5-A

Roentgenogram of fracture, two weeks after injury. Traction and closed reduction have failed.

and the fragment ends do not receive additional surgical trauma.

3. Impaction of the fragment ends is not desirable, physiological, or necessary.

4. Bone absorption of the fragment ends is automatically compensated for by longitudinal muscle tone; constant contact during the healing period is thus accomplished.

5. Fewer screws are necessary for controlled fixation; therefore, less bone trauma occurs.

6. The splint is flat, and pressure on the bone and periosteum is minimal.

7. Contact is accomplished with the least mechanical difficulty by permitting longitudinal motion in one or both ends of the splint.

8. As the irregular fragment ends are held in contact by muscle tone, the stability of the fracture is secure and torsion is controlled because the plate locks, due to physical forces.

9. There is less stress on the splint to break or bend it at the fracture site, because the space between the fragment ends of the bone, due to absorption, is eliminated.

10. Pressure in excess of eighty pounds has been applied repeatedly in the experimental laboratory to the long axes of bones, with no detrimental effect on the stability of the fracture site when the fragments are held in place by the splint.

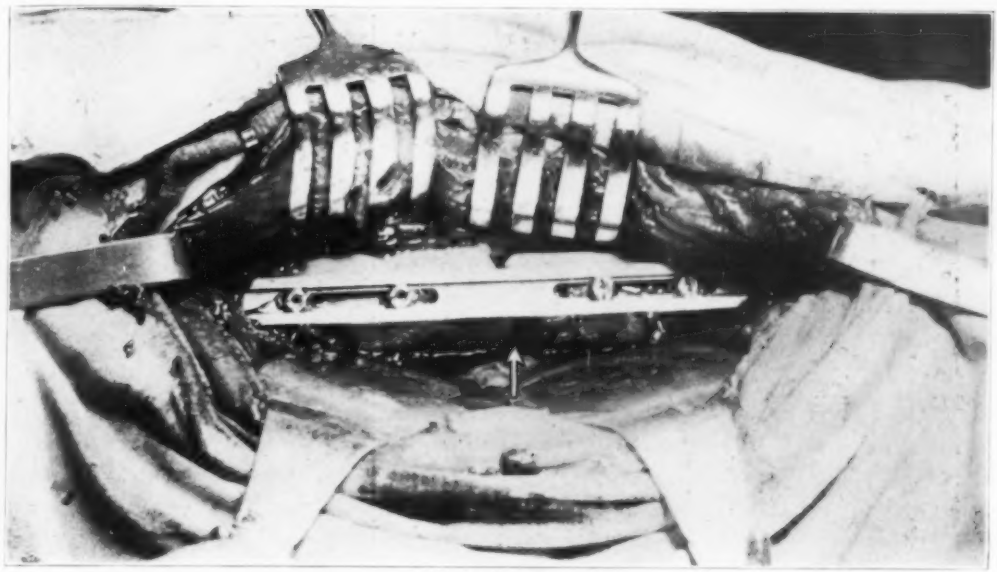

FIG. 5-B

Operative reduction and application of splint. Traction on extremity shows longitudinal mobility of the fragments.

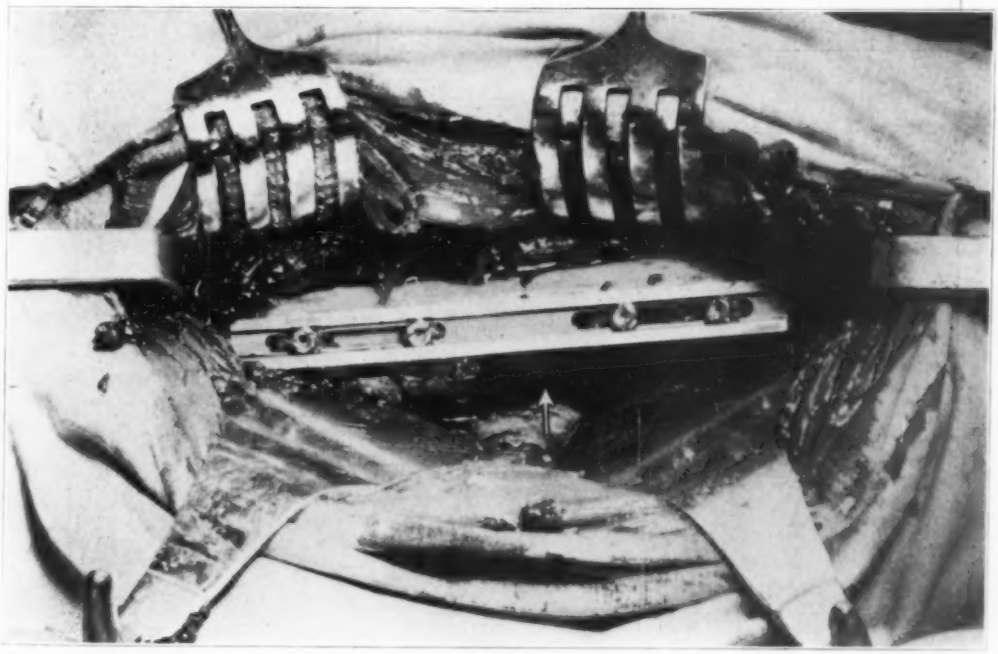

FIG. 5-C

Traction has been released, and fragment ends are in contact.

STABILITY TEST OF INTERNAL CONTACT SPLINT

The internal contact splint results in a dynamic accomplishment which can be understood more clearly if the following experimental procedure is carried out, thus permitting the surgeon a clearer appreciation of the principles involved:

1. A laboratory bone with an artificial fracture is prepared, and the splint is placed in position on the bone as in an operative procedure. The screws should be just loose enough on both sides so that the bone can be separated and united (Fig. 6).

FIG. 5-D

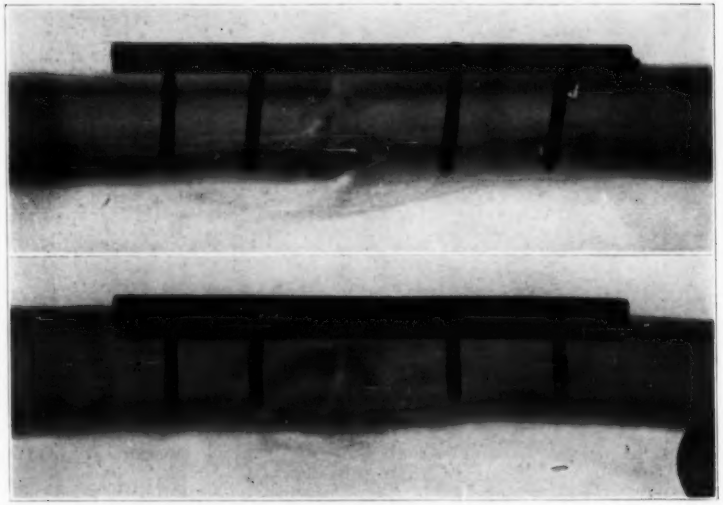

FIG. 5-E

Fig. 5-D: Nine weeks after reduction.
Fig. 5-E: Eleven weeks after reduction. Note changes in appearance of the fracture line.

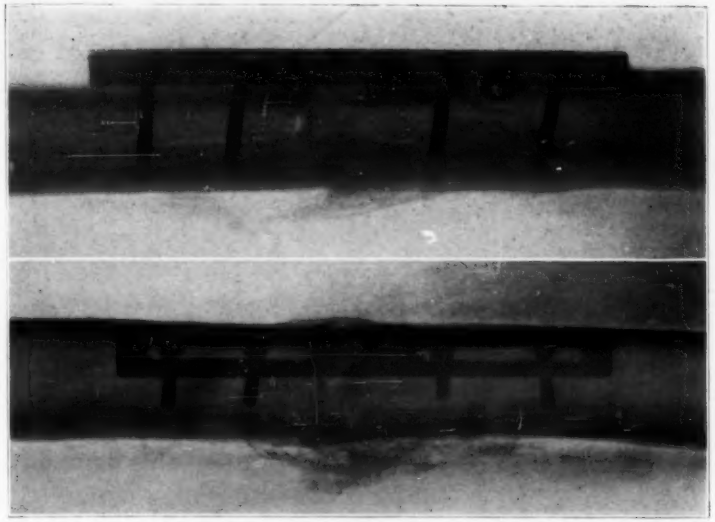

FIG. 5-F

FIG. 5-G

Fig. 5-F: Sixteen weeks after operation. Progressive improvement has occurred at fracture line, but little periosteal activity.
Fig. 5-G: Forty-two weeks after operative reduction.

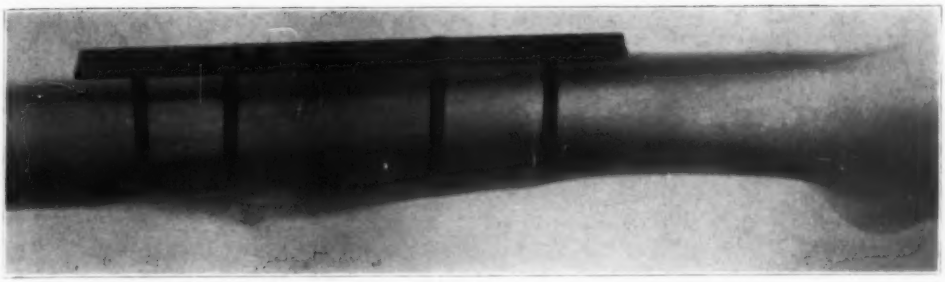

FIG. 5-H

Forty-two weeks after operation. Note union adjacent to splint, no atrophy of pressure, and union of the compact bone of the shaft,—the desired result.

2. One end of the specimen is held in the left hand and the opposite end is pressed against the chest, in order to simulate the longitudinal force exerted by the muscles in the clinical case. As the pressure is exerted, an attempt should be made to move the splint with the right hand, with the use of some type of instrument by which longitudinal pressure can be placed on the end of the splint. It will be found that the splint is actually in a locked position, due to the equilibrium of forces (Fig. 7). This assures stability, because the bone itself is bearing most of the strain. In immobilization with a rigid plate, the plate and screws must bear the greater part of the stress.

3. The second step of the procedure is repeated except that, before the fragment ends are pressed together, a thin piece of rigid metal is placed between them; then the longitudinal pressure is exerted. The intervening metal will be held in place by the pressure upon it. If the splint is checked, it will be found to be locked (Fig. 8). While the pressure is maintained, the intervening metal is pulled slowly; when the metal has been removed, the fragment ends will come into contact, and the splint again locks. This shows, even though the stability of the splint is secure, that the longitudinal migration of the ends is never prevented; and contact of the fragment ends during absorption of the devitalized bone is assured. Contact of the viable cortical bone is important, because its union is necessary for a successful recovery of the fracture. The low osteogenetic ability of compact bone

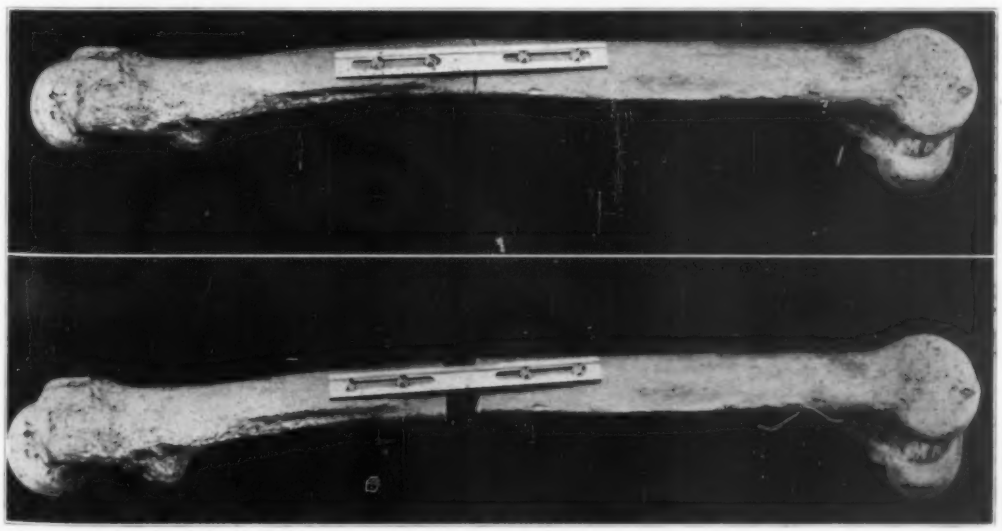

FIG. 6

Longitudinal muscle pull causes the fragments to glide into contact, because the screws are not tight.

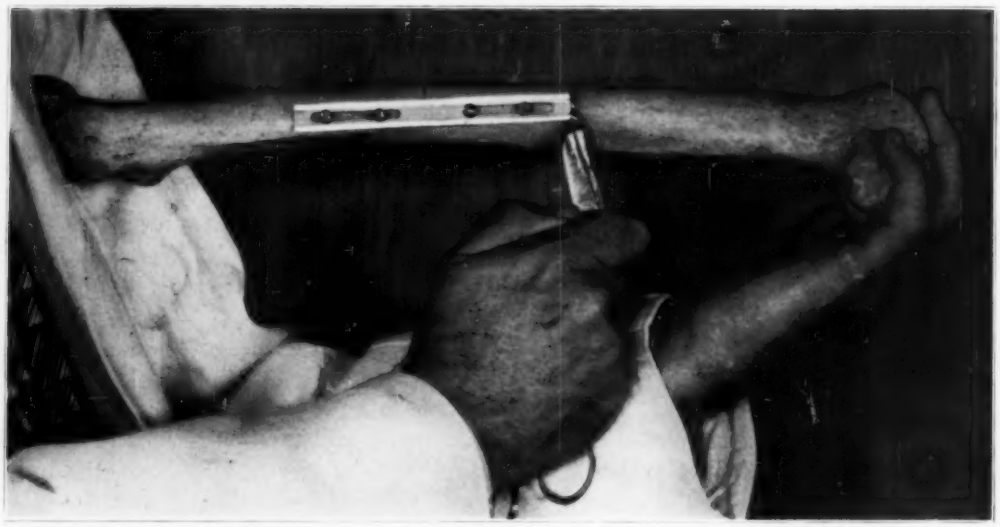

FIG. 7

As the longitudinal pull holds the fragment ends together, the splint locks, due to antagonistic geometric planes; thus the fracture is stable.

FIG. 8

An intervening strip is placed between the fragment ends; the longitudinal pull locks the splint and, in this case, the metal strip. If the longitudinal tension is continued and the metal strip is slowly pulled out, the bone ends immediately come into contact and the splint again locks. This assures continuous longitudinal mobility with constant locking of the splint.

requires close apposition of its viable elements for union. Irregularity of the fracture surfaces, when held together by the muscle pull, engage and control the rotary torsion.

SCREW PLACEMENT IN SPLINT APPLICATION

The application of the contact splint can be altered to accommodate the wishes of the operator. If there is any doubt in his mind that distraction may occur, he may place the first and fourth screws so as to touch the ends of the slots, and the second and third screws about one-quarter of an inch from the ends of the slots. Thus, the possible longitudinal migration of the fragments is only toward the fracture line, because its screws are not tight. This may be desirable in the femur, humerus, and tibia, as illustrated in the uppermost diagram of Figure 9.

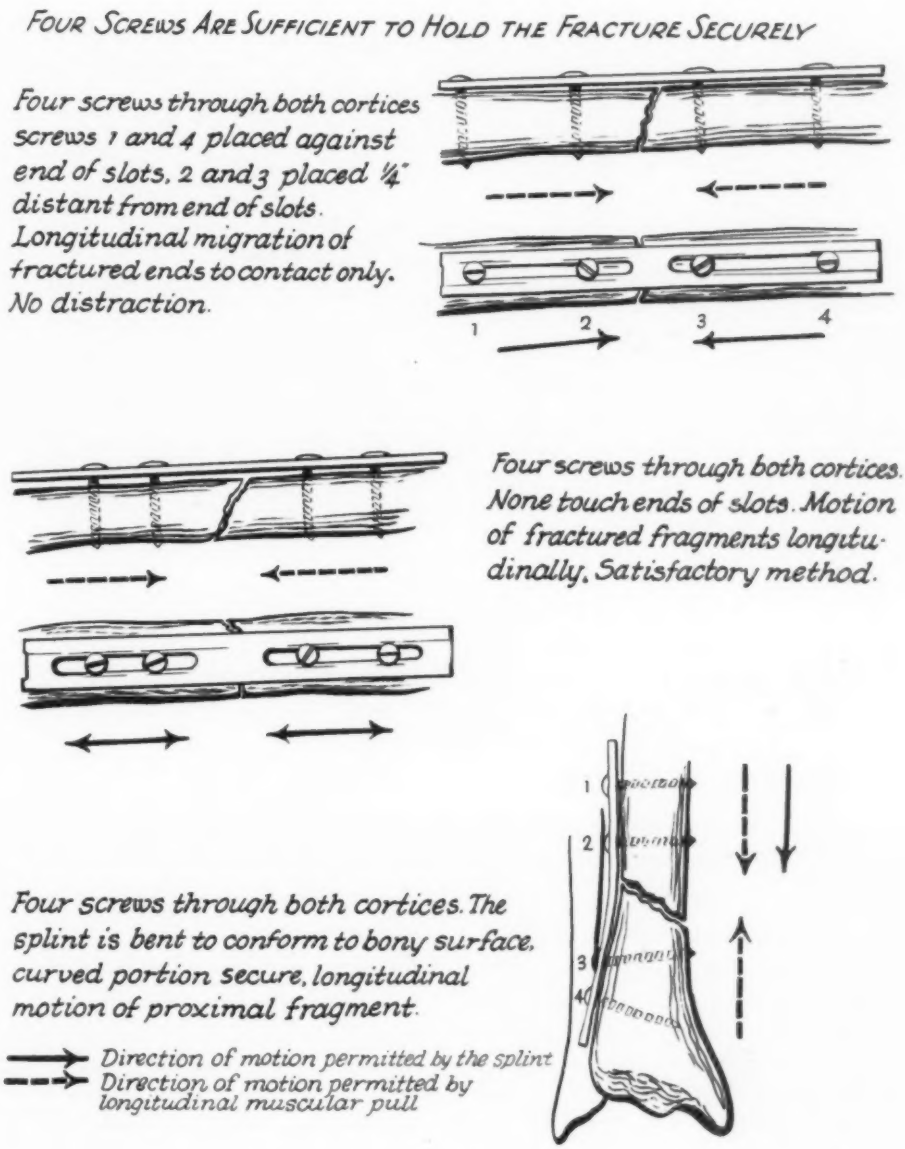
FOUR SCREWS ARE SUFFICIENT TO HOLD THE FRACTURE SECURELY
Four screws through both cortices screws 1 and 4 placed against end of slots, 2 and 3 placed ¼" distant from end of slots. Longitudinal migration of fractured ends to contact only. No distraction.
1
2
3
4
Four screws through both cortices. None touch ends of slots. Motion of fractured fragments longitudinally. Satisfactory method.
Four screws through both cortices. The splint is bent to conform to bony surface, curved portion secure, longitudinal motion of proximal fragment.
Direction of motion permitted by the splint
Direction of motion permitted by longitudinal muscular pull

FIG. 9

The middle diagram shows the application of the splint, a longer longitudinal excursion being allowed than in the method described in the preceding paragraph. All four screws (not tight) are placed a slight distance from the ends of the slots. This method is quite secure and satisfactory for the femur, tibia, and humerus, and particularly for the forearm. When the radius and ulna are splinted, a splint is placed on each end; in the application of the second splint, if traction is desired for reduction, the pull can be applied with the assurance that the fragments first splinted will simply glide apart and then return to the corrected position, supported by the splint when traction ceases. This feature is very helpful in increasing the ease of reduction and the application of splints to the radius and ulna.

The diagram at the bottom of Figure 9 illustrates the bending of the splint to conform with the curved surface of the bone. The curved portion is more stable if it is fixed firmly by placing the screws securely, permitting the gliding motion to occur in the area of the straight portion of the splint. The third and fourth screws are secure; the first and second screws are not tightened; and the fragments glide together for contact.

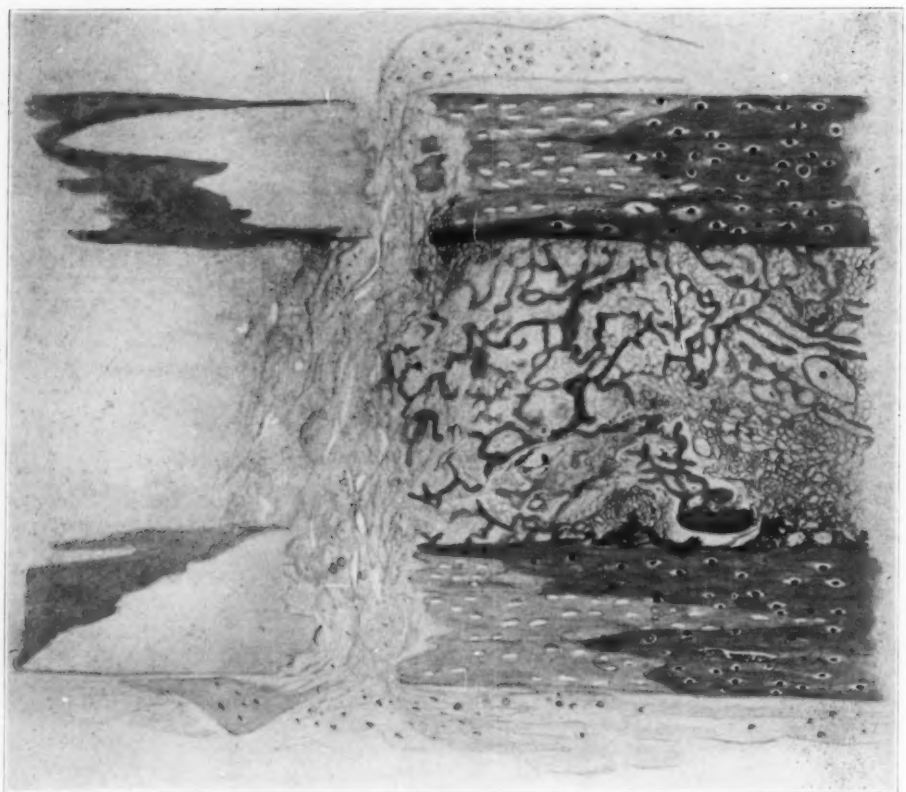

FIG. 10

Composite diagram of complete serial sections of fracture site, showing the areas of devitalization.

The important and necessary feature in the application of the contact splint is that it must allow longitudinal gliding of one or both fragments to assure constant contact.

To test the mobility permitted by the splint after application, anatomical traction must be applied before forceful sliding of the splint. The reason for this is that, when the bone fragments engage, due to the longitudinal muscle pull, the splint locks in position and, even though mobile, it will not move until the locking forces have been released.

Another method to test longitudinal mobility is to place a blade between the ends of the fragments, separate them slightly, and withdraw the blade; the fragments will then be approximated.

EXPERIMENTAL STUDY OF FRACTURE SITES

BY WILLIAM H. AINSWORTH, M.D., AND NORMAN E. WRIGHT, M.D., GALVESTON

The experimental healing of fractures has been studied and recorded many times, with emphasis upon the histological, biochemical, physiological, and clinical features. All of these studies indicate clearly that bone, a living connective tissue, possesses certain distinct characteristics which should aid in the clinical care of fractures. In this series of experiments, the microscopic or histological features of fractures were studied, the femora of large dogs being used as the bone of choice. These animals were divided into three groups of about ten dogs each. In the first group, a simple fracture of the femur was produced in a standardized manner in the anaesthetized animal; the dogs were sacrificed on the second, fifth, seventh, fifteenth, and twenty-first days. The second group of animals were sub-

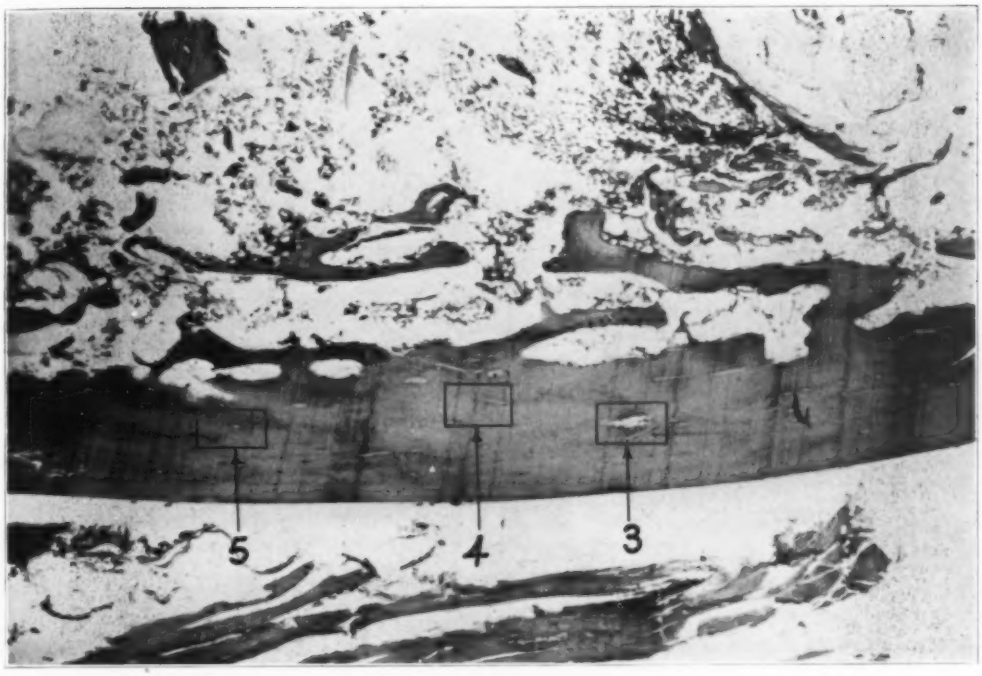

FIG. 11

Low-power study (× 40) of fracture site, to demonstrate areas from which higher magnifications were made.

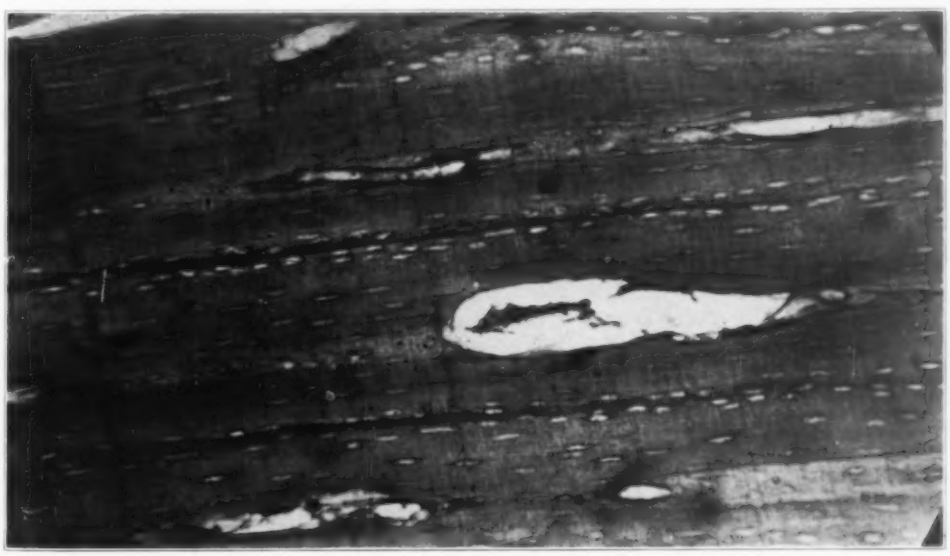

FIG. 12

Photomicrograph (×160) of cortex near fracture site, showing lacunae which have no cellular content. Haversian canals also demonstrate the devitalization. (Section corresponds to *3* in Fig. 11.)

jected to the same type of fracture, but immediately afterward the fracture site was opened and the two fragments were simply exposed to the air; reduction was accomplished; and the wound was closed without any attempt at fixation or immobilization. In the third group, after fracture and exposure of the fracture site, the ends of the fragments were traumatized directly by ten blows of insufficient force to cause shattering or splintering of the cortex.

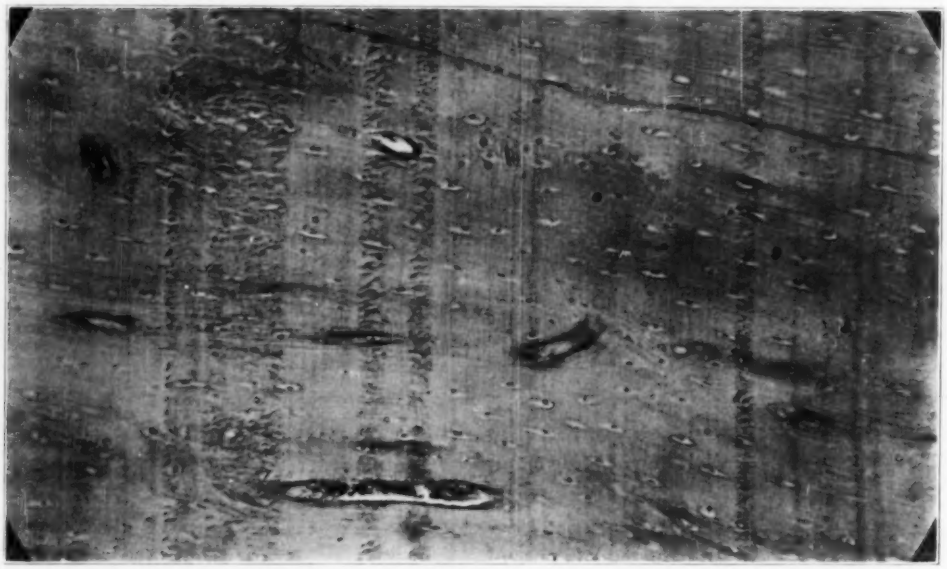

FIG. 13

Photomicrograph (×160) of cortex, showing devitalized cells interposed among living adult cells with normal Haversian systems. (Section corresponds to *4* in Fig. 11.)

FIG. 14

Photomicrograph (×160) of cortex, showing normal living adult cells well beyond the fracture site, for comparison with Figs. 12 and 13. Normal cytology is present. (Section corresponds to *5* in Fig. 11.)

Each of the specimens removed was decalcified in hydrochloric acid and paraffin and mounted with serial sections through the fragment end, including the neighboring soft tissues.

The microscopic study of the tissue thus prepared presented a picture which has previously been reported by Ham and others, but a further description may be of interest. Attention was directed especially to the cortical portion; and, in the area adjacent to the fracture, the numerous lacunae which normally house the mature adult bone cells were found to be entirely devoid of cellular content. This observation has previously been re-

ported, but the extent of the devitalization bears more careful observation (Figs. 10 and 11). It was also found that the lining of the Haversian canals, consisting of a single layer of cells, called the endosteum, and a small capillary, had undergone marked destruction (Fig. 12). Thus it is felt that not only does the trauma necessary to a disruption of the cortex cause the death of the adult bone cells, but that a circulatory factor must be present as well.

Moving away from the fracture site, it was next noted that there was no definite line of demarcation between living and destroyed cells, but rather that the two zones blended together very gradually (Fig. 13). The first evidence of living tissue was found in the Haversian system nearest the marrow cavity, with a few normal adult bone cells in the adjacent area (Fig. 14). However, more destroyed cells were found farther away from the fracture site. The area of bone nearest the periphery of the cortex showed the most widespread devitalization. The highly cellular content of the marrow cavity did not show the destructive changes, except in that small portion at the fracture site; and here they were present not longer than forty-eight hours, because at this time the cellular changes of repair proliferation were beginning. The experimental fractures which were simple showed the least amount of cortical devitalization. The area varied somewhat, and an accurate measurement was not attempted because of the blending of the two zones. Those fractures which were compounded surgically, although sustaining no more trauma, showed a much wider zone of devitalization than the simple fractures. The most widespread area of destruction was found in the third group of animals, in which trauma had been applied directly to the fragments in compounded wounds.

Thus, in reality, when a fracture of any nature is reduced, devitalized tissue is placed against devitalized tissue; and the removal of this must be accomplished in the physiology of healing before solid bony union occurs[3]. Although the fate of this inert cortical bone was not followed for more than twenty-one days, it was felt that this tissue enters very actively into the healing process[1] by its local effect on the chemical composition and reaction of the hematoma and granulation tissue. The drop[4] in pH during the first two weeks, and the relatively high calcium and phosphatase content of the bone and hematoma are certainly a result of this mass of cortical bone which has lost its blood supply. As the circulation in the area is restored with the formation of granulation tissue and primary callus, the components mentioned are changed.

NOTE: The authors wish to express their thanks, for help received in this work, to the Departments of Anatomy, Pathology, and Medical Illustration of the University of Texas School of Medicine; to the Austenal Laboratories; and to Miss Estelle Greenwalt.

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DISCUSSION

DR. ARTHUR G. DAVIS, ERIE, PENNSYLVANIA: It is difficult to discuss a new instrument of this kind, because of the lack of criteria by which to judge it. We cannot look to the experimental laboratory to furnish enough evidence to evaluate the importance of the various factors which seem to be of significance in the process of osteogenesis at the fracture line. On the other hand, clinical evidence has been accumulated during the last thirty-five years, including use of the Lane plate, Sherman plate, and the refinement of metals to the final point of the Murray type of plating with Vitallium or some other inert metal.

During the last twelve or fifteen years, my own experience with the Murray type of plating has been highly satisfactory. As you all know, the Murray procedure aims at a hair-line apposition, the complete

elimination of all motion, and the elimination of shear strain at the line of fracture. The plate is put on vertically and a screw or two transfixes the fracture line at right angles to the direction of the plate, in order to eliminate shear strain and other oscillations.

Dr. Eggers's method at first glance appears to neglect these seemingly important factors. Dr. Eggers sent me his complete paper and a contact splint for experimentation. At first I could not understand how this plate could hope to eliminate the various kinds of stress encountered at the fracture line. In a transverse fracture, jamming the two fragments could eliminate shear strain; but in an oblique fracture, the impaction seemed impossible. Further study, however, showed that what actually happens with this adjustable plate mechanism is that, regardless of whether the fracture line is oblique, transverse, or irregular, the fragments become jammed the moment there is compression strain, as must inevitably be present as soon as the patient becomes conscious. Demonstrations on the skeletal specimen proved unconvincing. In order to visualize the manner in which the automatic adjustable mechanism works, one must assume the conscious patient and the fact that there is immediate muscle contraction; also the fact that all long bones are contained within a fascial compartment. The resultant of the total muscle contraction in kinetic energy, released in the fascial compartment containing the bone, must obviously be in the longitudinal axis, since most muscles contract parallel to the axis of the long bone. As the axial strain is imposed, the two main fragments slide toward each other as though mounted on a rack. As they become impacted, the horizontal elements of motion at the fracture line are also eliminated by the lateral and oblique thrust from one impaled fragment against the screw heads and plate transfixing the other main fragment. Thus it is clear that the contact splint has the potential of that highly desired state at the fracture line,—elimination of all abnormal motion. It also has the definite advantage of future adjustment or jamming in a case which has been badly done technically. If there is distraction with the ordinary plate, this distraction persists. The contact splint does not permit such distraction to persist.

Dr. Eggers has described his operation in detail and has cited forty cases. He does not, however, cite the outcome in each case or state whether or not they are consecutive. Because of the success of the Murray technique when properly executed, I personally would be loath to abandon it for this new and as yet unproved method. However, I am definitely interested in following the evidence, because of the sound principles involved.

In this meeting we have had another corroborative piece of work, submitted by Dr. Phemister; this method is specifically for pseudarthrosis. Nevertheless, the same principles are exhibited in his work, and his very impressive results speak for themselves. If my interpretation of his method is correct, it is because of the compression strain, regardless of the graft, that calcification of the intervening fibrous tissue between the bone ends is actually obtained in his cases. We believe that this happens because the shear strain is converted into a compression strain, just as it is by doing a Shantz osteotomy for non-union of the hip. Evidence such as this tends to underline the importance of compression strain as a factor in both bone growth and fracture healing, since it is always present and, in the normal conscious human, forms part of the natural environment of the growing bone or of the bone undergoing repair. What, then, do we need by way of evidence to pass judgment on this method? Evidence is only as significant as the number of cases involved, plus the fate of each case in a consecutive series. If, for example, Dr. Eggers were to submit a consecutive series of one hundred cases, analyzed from the point of view of the patient's return to his former occupation, time of structural union, incidence of non-union, delayed union, and foreign-body reaction, we could then hope to evaluate this new and promising method. I am definitely interested in this method, and hope to keep in touch with Dr. Eggers' work as it proceeds.

DR. ALFRED O. ADAMS, SPOKANE, WASHINGTON: A few years ago, when we were doing limb-lengthening operations, we devised a means of determining accurately the amount of lengthening that had been obtained. A metal ruler, through which drill holes had been placed, was fastened to the lower extremity at the time the roentgenogram was taken. The same principle could be used in fractures, where fixation with a slotted plate is used, to determine how much absorption of the bone actually takes place.

This slotted plate could be marked as a ruler, in such a manner as to be recorded on the roentgenogram, and the distance between two screws, one in each fragment, could be measured soon after operation and at intervals until union occurred.

The position of the screws would remain the same in the bone, and any change in the distance between these two screws would be due to absorption of the ends of the fragments.

DR. HAROLD E. CROWE, LOS ANGELES, CALIFORNIA: We have all seen roentgenograms in which internal fixation with various kinds of metal held the fractured bone ends apart. Following the normal absorption of fractured bone ends, a gap must necessarily appear, and the internal fixation results in maintaining separation of the fragments. We have watched these metal plates bend in order that the bone ends, in their struggle to get together and produce union in spite of the interference of surgeons, might make contact and go on to union with important angulation. I am delighted that Dr. Eggers has had the courage to undertake this type

(*Continued on page 115*)

AN ANATOMICAL STUDY OF THE MECHANICS, PATHOLOGY, AND HEALING OF FRACTURE OF THE FEMORAL NECK

A Preliminary Report * †

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From the Departments of Orthopaedic Surgery and Anatomy, New York Medical College, Flower and Fifth Avenue Hospital, and Metropolitan Hospital, New York City

In search of a better understanding of fracture of the femoral neck, the anatomy and mechanics of the upper portion of the femur were subjected by the authors to a thorough study. Most questions relating to the problem, although apparently settled, were re-examined, with the result that we have revised our views of both the generally accepted crane theory of weight-bearing in the hip region and the important anatomical factors and healing mechanism in fracture of the femoral neck. Both the mechanics and the physiology of the femoral neck depend upon a bony system within the neck, which has hitherto received little attention.

The investigation took the following course: After dissection of the upper portion of the shaft and of the neck and head of the femur in normal specimens, and after roentgenographic analysis, miscroscopic examination of each structure was carried out. As the next step, the mechanical implications of the findings were studied in living persons in different age groups, by means of roentgenograms.

On the basis of the anatomical study, the pathology of fracture of the neck of the femur was re-examined, with particular reference to the discrepancy between the rapid healing of abduction fractures, with little or no treatment, and the slow healing or non-union of adduction fractures, regardless of treatment. Furthermore, the mode of trauma was studied. In abduction fractures the trauma is almost invariably a fall on or compression of the trochanteric region, while many adduction fractures, especially in the aged, are preceded by trauma which is seemingly insufficient to produce the injury. Thus in adduction fractures, some definite pathological changes in the femoral neck preceding the fracture had to be supposed, an assumption encountered both in the older and in the more recent literature [2, 13]. This assumption has been confirmed by the present study.

Finally, a new surgical method was developed and applied.

For the anatomical study, the bone marrow of the upper portion of the femoral shaft and of the neck was curetted out, with only light touches of the curette. After removal of the cortical shell of the anterior aspect of the femoral neck, the well-known trajectory system appears (Fig. 1). This consists of rather weak, spongy spicules, which yield easily to the curette. When, however, from one-eighth to one-quarter of the thickness of the neck close to the head has been removed, the curette strikes a bony structure almost as hard as cortical bone, roughly quadrangular in shape, and composed of a large number of closely packed lamellae (Fig. 2). This structure seems to spring from the inferior cortex and to spread from it, tending to extend partly toward the superior aspect of the cortex of the neck and partly toward the cartilaginous plate, where it terminates.

To have a better understanding of the extent of the structure, the lateral wall of the upper portion of the femoral shaft was removed, from the region of the greater trochanter to below the level of the lesser trochanter (Fig. 3-A). After the removal of the cortex, the spongy bone was curetted out until the instrument met a structure which felt like cortical

* This study was carried out under a grant of the Research Committee of the New York Medical College.
† Submitted for publication on January 27, 1947.

FIG. 1

FIG. 2

Fig. 1: Frontal section of the femoral neck and head in normal specimen from an older individual.
A: Trabeculae of the internal weight-bearing system may be seen entering the head.
Fig. 2: Frontal section of the femoral neck, after the spongy tissue has been curetted out.
A: Proximal end of the internal weight-bearing system with cartilaginous plate.
B: Supporting pillar for the internal weight-bearing system, arising from the upper cortical shell.
C: Cartilaginous plate.

bone. When this bony framework was followed toward the interior of the neck, it was found that it formed a bony septum, which apparently fused with the posterior cortex of the neck. It originated from the posterior and inferior aspects of the femoral shaft, two to four centimeters below the lesser trochanter. Toward the neck it turned posteriorly and apparently fused with the posterior aspect of the neck, near its center.

Beneath the postero-inferior wall of the neck, both the origin and the proximal termination of the bony system can be seen, with a cortical ridge connecting them (Fig. 4-A).

If, however, the whitish cortical covering of the ridge is chiseled off, which ought to be done carefully, the true extent of the system is disclosed (Fig. 4-B). Underneath the cortical layer of the connecting ridge, the same lamellar system is to be seen as throughout the course of the structure. It is then obvious that we are dealing with one *uninterrupted* lamellar system, running from below the lesser trochanter to the region of the cartilaginous plate, forming the proximal anchorage of the system. This largely independent bony framework is from ten to twelve centimeters long (Figs. 3-B, 5-A, and 5-B).

Even without removal of the cortical layer, in specimens representing a frontal section of the neck, the system may be recognized as clearly of different structure from the cortex, continuous in its course, and of laminar nature.

The system lines the inferior and posterior aspects of the neck. At the head it is strengthened by a strong pillar, also of laminar nature, springing from the superior aspect of the neck and joining the system just before it enters the head (Fig. 2,*B*). Throughout its course, the system as a whole and each of its individual laminae are enveloped by bone marrow. At and in the head it forms approximately the middle two-fourths in both the sagittal and frontal planes, while the anterior and posterior fourths are formed by bone marrow embedded in delicate cancellous bony framework (Fig. 6).

The relationship of the system to the cortical tube of the neck is of great importance. It can be seen, both in specimens and roentgenograms, that there is a reciprocal relationship between the strength of this structure and that of the cortical shell. The system is

FIG. 3-A

FIG. 3-B

Fig. 3-A: Normal specimen from proximal end of the femoral shaft, in the lateral aspect. Cortex has been removed.

A: Beginning of the internal weight-bearing system below the lesser trochanter.

B: Bony septum formed by internal weight-bearing system, entering the neck.

Fig. 3-B: Same specimen, seen from below after removal of the inferior aspect of the femoral shell.

A: Internal weight-bearing system.

B: Margin of posterior aspect of cortical shell, separated from internal weight-bearing system.

FIG. 4-A

FIG. 4-B

Fig. 4-A: Normal specimen of femoral neck, after removal of the inferior aspect of the cortex. *A:* Origin of the internal weight-bearing system.

B: Cortical layer covering the internal weight-bearing system. *C:* Termination of the internal weight-bearing system.

Fig. 4-B: After removal of the common cortical covering of the internal weight-bearing system and posterior aspect of the neck from same specimen.

A: Internal weight-bearing system. *B:* Posterior aspect of the femoral cortical shell, as clearly separated from the internal weight-bearing system.

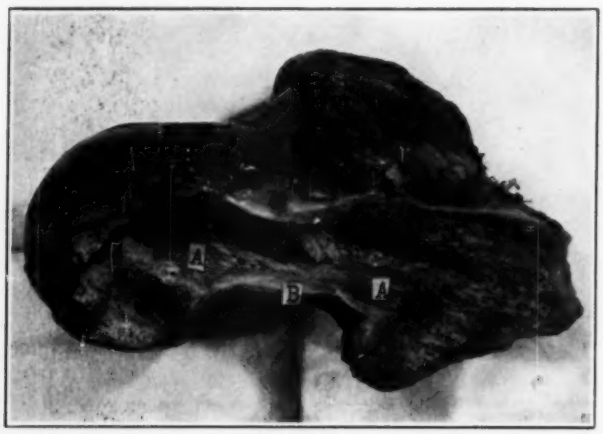

FIG. 5-A

FIG. 5-B

Fig. 5-B: Roentgenogram of specimen shown in Fig. 5-A. *A:* Internal weight-bearing system. *B:* Cortex.

FIG. 6

Fig. 5-A: Specimen from an older individual. Inferior aspect of the cortex has been removed.

A: Internal weight-bearing system, extending from below lesser trochanter to head. Note laminar character throughout its course.

B: Inferior aspect of cortical shell, clearly separated from laminar internal weight-bearing system.

Fig. 6: Normal specimen after removal of parts of posterior aspect of cortex at the juncture of the head and the neck. Note the internal weight-bearing system as a massive cortex-like, whitish pillar, entering the head.

weakest at its point of apparent fusion with the neck, where the cortical bone reaches its greatest strength; while at the point where the system enters the head in fanlike fashion the cortical bone is the thinnest,—as a matter of fact, it is hair thin at the juncture of the head and the neck (Figs. 2 and 7-A). The significance of this arrangement in the mechanics of weight-bearing and in the pathology of fractures will be discussed later in this study.

After middle age the system starts to undergo slow resorption, beginning at its distal portion. At the same time, the cortical layer at the site of the apparent fusion of the structure with the neck gradually becomes thinner. In older patients the proximal portion becomes more brittle, the spaces between the laminae larger, and the number of laminae smaller (Fig. 7-B). In still older patients, around the ninth decade, the laminae at the distal portion of the neck appear to the naked eye as hardly larger collectively than one of the normal cancellous laminae. The bony structure, representing the cartilaginous plate of adolescence, gradually disintegrates and ceases to be the proximal point of anchorage of the system. After the dissolution of this structure, the laminar system continues directly to the articular cartilage of the head.

Although the distal portion becomes partly resorbed, the system is maintained throughout life. We have never failed to find it, even in the hips of patients close to one hundred years of age.

FIG. 7-A

FIG. 7-B

Fig. 7-A: Anteroposterior roentgenogram of the entire internal weight-bearing system, from below the lesser trochanter, in a younger individual. The laminae are closely packed as they enter the head.

Fig. 7-B: Roentgenogram of the internal weight-bearing system in an older individual. Laminae entering the head are widely spaced and loosely packed; individual laminae are clearly seen. Site of cartilaginous plate is in a state of dissolution.

FIG. 8

FIG. 9

Fig. 8: Oblique roentgenographic view of the femoral neck.

A: Internal weight-bearing system is represented as a triangular shadow, running from the lesser trochanter into the head. This form of the internal weight-bearing system is not uncommon.

Fig. 9: Lateral roentgenographic view of the internal weight-bearing system.

A: Internal weight-bearing system skirting the lesser trochanter.

B: Site of apparent fusion between internal weight-bearing system and posterior aspect of neck.

On the roentgenogram, the proximal portion is seen best on the anteroposterior view, the distal portion on the oblique and lateral views. The oblique and lateral views show the structure as a bony ridge or septum between the greater and lesser trochanters. Roentgenograms clearly show that the structure originates below the lesser trochanter, which it skirts from one to two centimeters anteriorly in its course toward its apparent fusion with

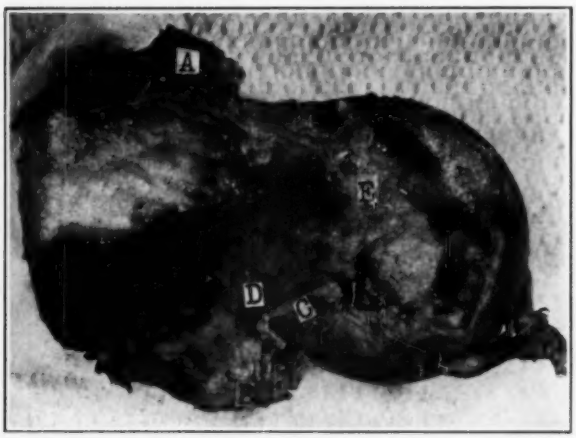

FIG. 10

FIG. 10

Specimen of neck and head of normal femur in an individual, eighty-four years old. Inferior aspect of the cortical shell has been removed. Internal weight-bearing system is preserved in almost its entire course.

A: Greater trochanter.

B: Lesser trochanter.

C: Posterior cortical shell separated from internal weight-bearing system.

D: Distal portion of internal weight-bearing system, of dark reddish color.

E: Proximal portion of internal weight-bearing system, of whitish color.

the neck (Figs. 8 and 9). In advanced age the roentgenograms show that the system is composed of laminae throughout its course; furthermore, the proximal laminae gradually become more and more separated, less numerous, and more loosely packed (Fig. 7-B). Another phenomenon may be observed in old age. Although the entire distal portion of the system is normally of reddish color, from the site of its apparent fusion onward to its termination, in the aged the reddish color turns whitish-yellow without transition from one color into the other (Fig. 10).

The microscopic examination, to be reported in detail in a forthcoming study, shows that the system consists of a large number of strong, spongy laminae with wide marrow spaces between them. It is endowed with a large number of bone cells and is lined with

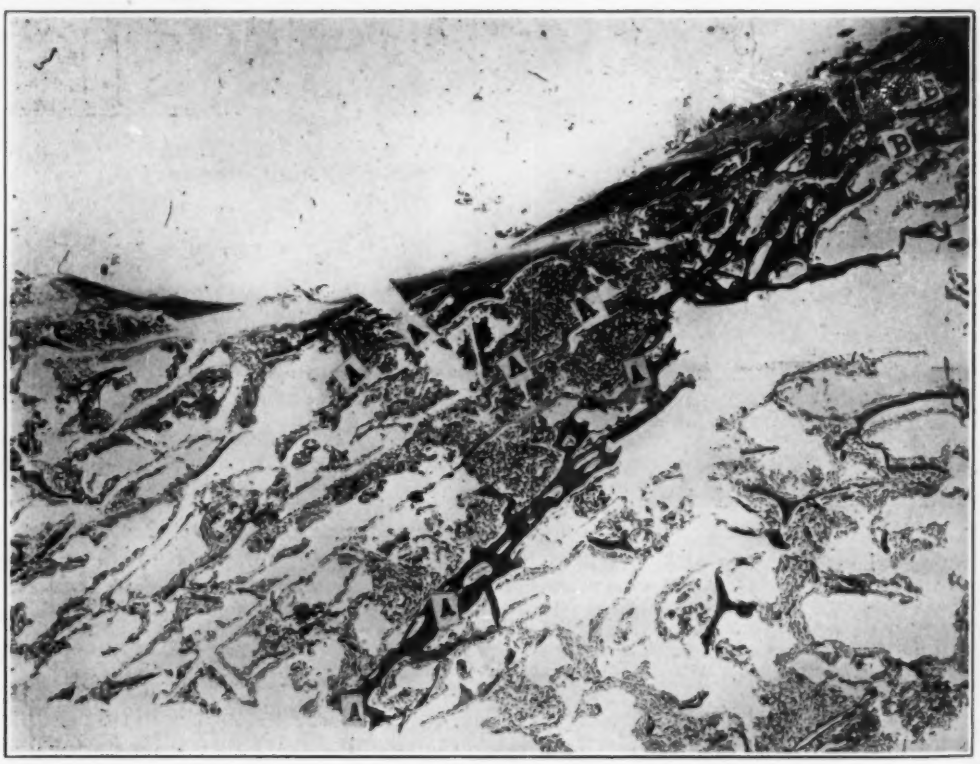

FIG. 11-A

Photomicrograph (× 8) shows the internal weight-bearing system, traversing the bone marrow, as it approaches and reaches the site of apparent fusion with the cortex. Note rich laminar character.

A: Internal weight-bearing system traversing bone marrow.

B: Site of fusion, — the weakest spot in the course of the internal weight-bearing system.

FIG. 11-B

Photomicrograph (× 100) taken from Fig. 11-A at *B*. Note the large number of cells, marrow spaces, and the endosteal lining.

highly cellular endosteum (Figs. 11-A to 11-E, inclusive). Histologically, it is similar to the spongy laminae of the iliac bone.

Reviewing the literature concerning the inner structure of the femoral neck, the authors found references to parts of the distal portion of the system under discussion. In 1844, Rodet described a cortical plate at the lesser trochanter and called it "*lame sous-trochantinienne*". Merkel called it "*Schenkelsporn*" or "*calcar femorale*"; Bigelow, "the true neck of the femur". Krause and Dixon refer to it as "*Lamina femoralis interna*". Dixon followed the lamina from the lesser trochanter up to its merger with the femoral neck. All authors agree that the lamina disappears completely after middle age, although Bigelow believed he had seen traces of it in some specimens in old age. No histological examinations have been reported. The femoral spur, the significance of which none of the authors could disclose, is part of the structure under discussion. Its complete resorption in old age is normally only apparent, not actual, as only its cortical covering disappears, and to the naked eye it does not stand out among the great number of laminae at the lesser trochanter. The roentgenogram and curettage reveal its presence throughout life.

The significance of the bony system in the interior of the femoral neck is threefold: (1) It is intimately connected with weight-bearing; (2) it is the chief source of bone repair; and (3) its transformation and partial resorption in old age comprise the main pathological factor preceding fracture of the neck of the femur, especially in the aged.

The mechanical implications of the system will be reported in detail in a separate study. Roentgenographically, it can be demonstrated that the structure is the *internal*

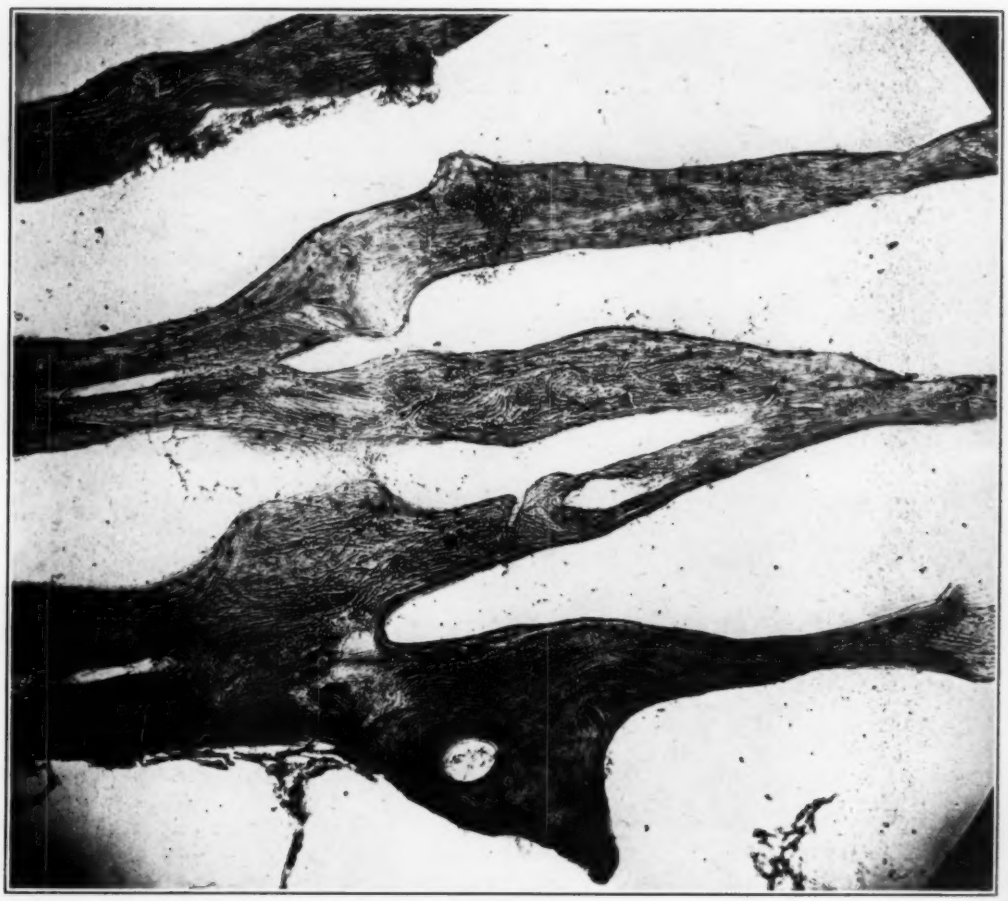

FIG. 11-C

Fig. 11-C: Photomicrograph (× 100), taken from Fig. 11-A at *B*, shows internal weight-bearing system after it leaves the site of apparent fusion and spreads out toward the head. A large number of individual laminae, which had been separated from one another and later connected by means of interlacing laminae, may be seen. The spaces between the individual laminae were originally filled with bone marrow, washed out during preparation. Note the slender laminae as compared with the large interspaces, the large number of bone cells, and the endosteal lining.

Fig. 11-D: Part of one of the laminae (× 600). Note the longitudinal arrangement of rows. The endosteal lining at one place indents the lamina in a baylike fashion.

Fig. 11-E: Individual lamina "sandwiched" between two wide layers of bone marrow, offering abundant nourishment for the normal lamina and taking care of its union after injury. Note the large number of cells on the laminar surface, and also the uninterrupted endosteal lining of the lamina (× 100).

weight-bearing system of the neck of the femur, forming an angle of from 3 to 8 degrees with the perpendicular during weight-bearing in youth and throughout middle age.

Walkhoff, in an excellent roentgenographic study, taking a stand against the crane theory of Meyer and Culmann, called attention to the heavy, spongy trajectories originating at the cortical shell of the neck and ending at the joint cartilage. He called them "*Trajektorien der aufrechten Haltung*" (trajectories of the erect position), and regarded them as spongy laminae which increased in strength as a result of weight-bearing. Although he failed to inquire into the anatomical nature of his roentgenographic findings, he proved his point to a great extent. He showed that the trajectories at the proximal end of the neck were completely missing in the primates and quadrupeds, and were poorly represented in the Neanderthal and Spy men. Walkhoff also found that, after the healing of fractures of the neck of the femur, only the dense trajectories running into the head were reformed, while the others failed to rebuild. His trajectories of the erect position are represented by the proximal terminus of the system under discussion. Walkhoff's con-

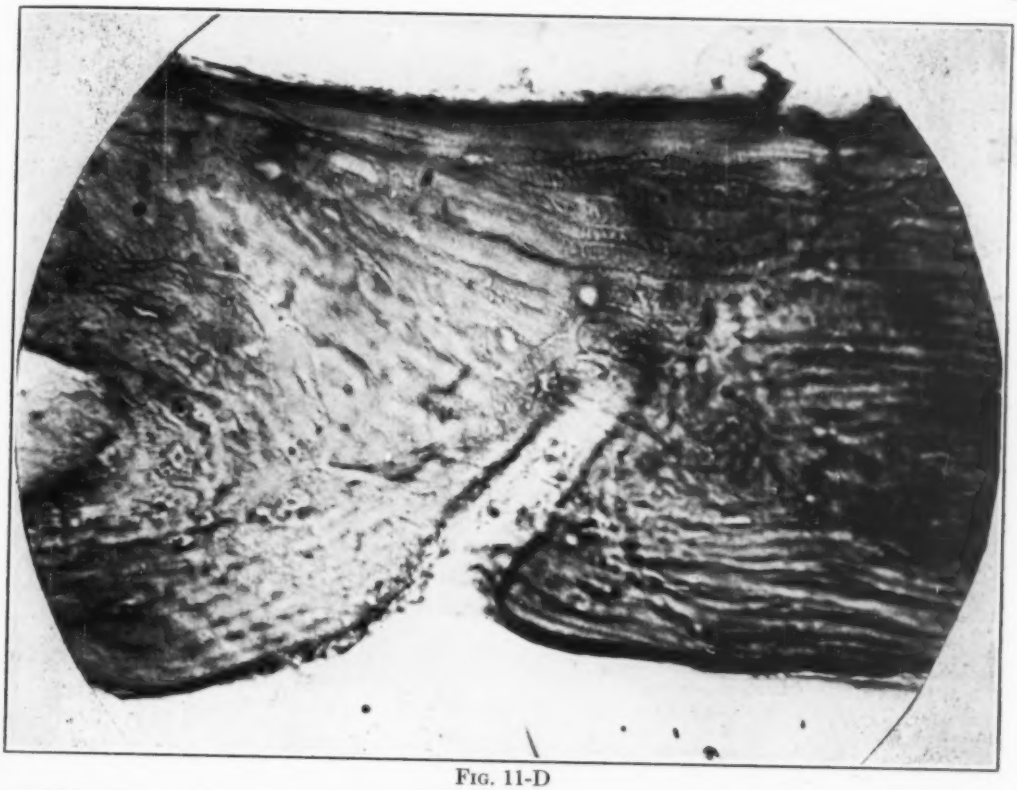

FIG. 11-D

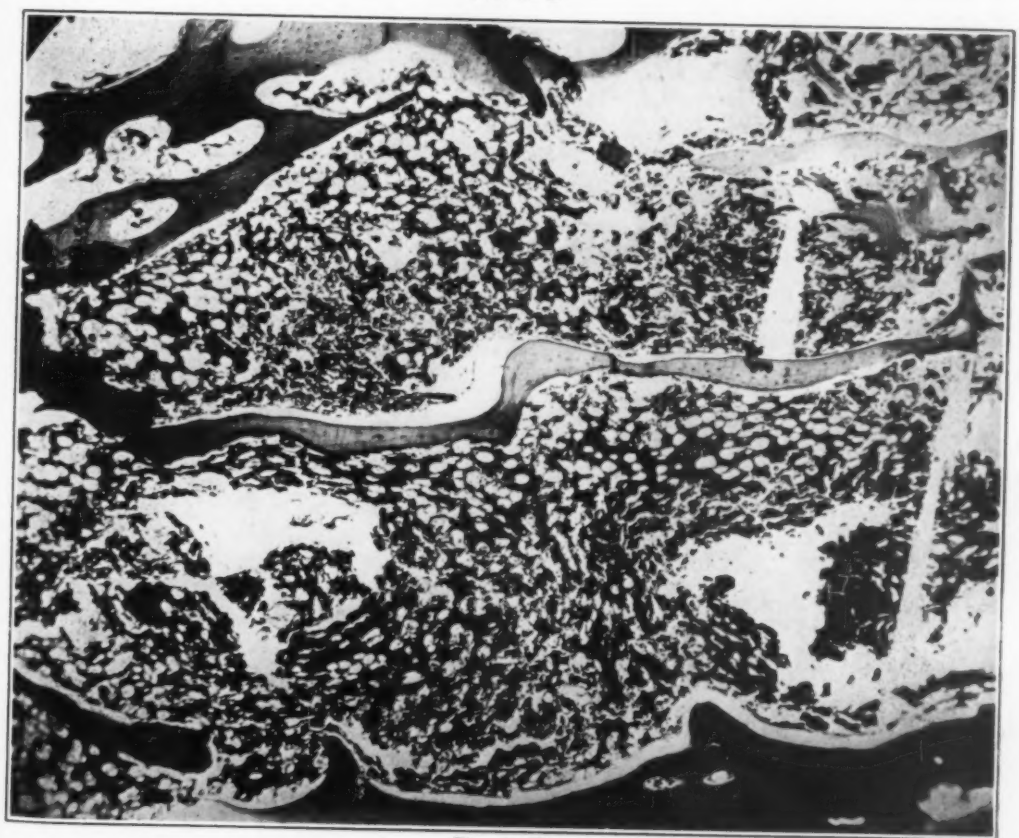

FIG. 11-E

FIG. 12

FIG. 13

Fig. 12: Anteroposterior roentgenogram after successful shelf operation for congenital dislocation of the hip. (*Courtesy of Dr. Leo Mayer.*)

A: Internal weight-bearing system below the shelf increased in strength and shifted to the vertical plane.

Fig. 13: Lateral view of femoral neck of eight-year-old boy. Cyst replaces the spongy structure of the upper shaft and neck. The internal weight-bearing system is preserved in its entire course. (*Courtesy of Dr. Leo Mayer.*)

ception is correct according to our analysis (to be reported later), in which we resorted to the roentgenographic method of investigation of weight-bearing at the hip.

In pathological conditions, when the mode of weight-bearing changes, the internal weight-bearing system always shifts to the line of weight-bearing. In subluxations of the hip and after shelf operations, for example, the system is greatly strengthened and shifted to the vertical plane (Fig. 12).

In congenital dislocations, without a rigid plane of weight-bearing, the system is reduced to a few laminae; in cases of ankylosis in which the weight is distributed all over the head of the femur, the system is scattered throughout the entire head.

Concerning the crane theory of the hip, Koch remarked: "It will be seen that the trabeculae lie exactly in the paths of the maximum tensile and compressive stresses . . .". The authors doubt that any tensile stresses are present around the hip joint. The system under discussion is a purely compression system, and the authors have not observed any other trajectories serving weight-bearing and the changes thereof. In addition, there is an important physiological fact, hardly compatible with the presence of tensile stresses: The epiphysis of the femur would normally show slipping in every human being, if tensile stresses amounting to two or three hundred pounds arose at its site, as the epiphyseal line could hardly withstand such an enormous displacing force.

Thus the bony structure under discussion appears to be the internal weight-bearing system of the neck of the femur, a compression system and apparently the only spongy structure in the femoral neck serving weight-bearing. Its physiological value is apparent in the case of cysts in which the entire spongy structure of the femoral neck has become resorbed, except that the internal weight-bearing system remains preserved, as an entity, as does the cortical shell (Fig. 13).

The role of the internal weight-bearing system in bone repair can best be observed during the healing of fractures of the neck of the femur. Being a spongy laminar structure,

FIG. 14

FIG. 15

Fig. 14: Lateral roentgenogram of an abduction fracture of the femoral neck, four weeks after injury.
A: Fracture line of the internal weight-bearing system at the end of the proximal cone.
B: Fracture line of the cortical shell, along the neck.
C: Fracture line of the cortical shell at the juncture of the head and the neck.

Fig. 15: Anteroposterior view of abduction fracture of the femoral neck. Note that the laminae are bent only, and not broken, as in a greenstick fracture.

extremely rich in bone and endosteal cells, beset with marrow spaces—the individual laminae, as it were, "sandwiched" between layers of bone marrow—it biologically represents the bony structure which shows the safest and speediest medium of bone repair among all bony tissues (Figs. 11-A to 11-E, inclusive). The experiments of Matti, Ghormley and Stuck, Dick, and others with grafts—taken in some cases from the iliac bone and in other cases from the lateral aspect of the femur (the region crossed by the internal weight-bearing system)—proved the unique value of this type of tissue in bone repair.*

The experiments of Bergmann with bird bones, which possess air holes in place of bone marrow, show the paramount importance of the endosteum. After the experimental fracture of the long bones of birds, the examination of the healed fracture showed that the bony cavity, until then empty, was filled with endosteum, developed from the few endosteal cells apparently indispensable in bone repair.

All this implies that in fractures of the femoral neck, if the internal weight-bearing system is strong and healthy and its fragments are in close apposition, speedy and safe healing may be expected; while, if the internal weight-bearing system has undergone pathological changes, healing of the fracture with normal function is at least improbable. The pathological changes in fractures of the femoral neck seem to confirm this supposition.

For the present study, eight specimens with fracture of the neck of the femur were available,—seven of them with ununited fracture of the femoral neck, and one with a healed fracture. Before examination of the pathological specimens, roentgenographic analysis of a large number of cases of fracture of the neck of the femur was carried out with special reference to the internal weight-bearing system.

In the *abduction* fractures, it was noted that fracture of the internal weight-bearing system and of the cortical shell usually occurs at their weakest points. The internal weight-bearing system breaks around the middle of the neck; and the cortical shell, at the cervico-capital juncture. Therefore, a fracture plane results which is wedge-shaped at the distal

* At the proximal end of the humerus the roentgenogram reveals a system resembling that under discussion. The presence of such a system may account for the speedy and safe healing of fractures in this region, frequently encountered even in the aged.

portion, where the separation of the internal weight-bearing system takes place; from there it runs parallel with the cortical bone, vertically broken at the point where the neck joins the head (Fig. 14). In many instances of abduction fracture, one may see the internal weight-bearing system in the state of a green-stick fracture (Fig. 15). This may account for the rapid healing without treatment. The reason for the lack of displacement in such fractures, even if the internal weight-bearing system has been completely separated, is the possibility of impaction by dint of the great number of laminae, derived from the system, being pushed and hooked into one another. The fast healing of such fractures results from the biological nature of the internal weight-

FIG. 16

FIG. 16

Specimen of a healed adduction fracture of the femoral neck. Inferior cortical shell has been removed.
A: Posterior wall of the neck.
B: Anterior wall of the neck.
C: Internal weight-bearing system, in marked proliferation and callus formation.
D: Callus, originating from the internal weight-bearing system, bridging posterior and anterior walls.
E: Callus, originating from the internal weight-bearing system, filling fracture line between head and neck.
F: Remnants of capsule, engulfed by callus.

FIG. 17-A

FIG. 17-B

Fig. 17-A: Specimen of an ununited adduction fracture of the femoral neck, six weeks after injury. No distinct internal weight-bearing system can be seen.
A: Posterior wall of the neck is greatly increased in width as a result of possible conversion of the internal weight-bearing system into cortical bone.
B: Newly formed laminae, originating from distal fragment, closing off the distal fragment from the proximal one.

Fig. 17-B: Anteroposterior roentgenogram of same specimen.
A: Cortical shell is greatly increased in width. No separate internal weight-bearing system can be seen.
B: Lamina sealing off the distal fragment.

bearing system, as previously pointed out. Also in *adduction* fractures, the healing of the fracture is fast and uneventful, if the fragments of the internal weight-bearing system are in good apposition and the structure is of normal composition.

The roentgenographic signs, in fracture of a bone with a normal internal weight-bearing system, are the following: The laminae are numerous; they are densely packed; the proximal fragment of the internal weight-bearing system is long; its end is blunt and not pointed. Naturally, the proximal fragment of the structure has to be brought into contact with the distal fragment of that system. Distraction of the fragments of the internal weight-bearing system may bring about non-union.

In fractures of bones with a normal internal weight-bearing system, the site of the separation of the structure usually does not coincide with that of the cortical shell. Almost all fractures belonging to this group are caused either by a fall on the region of the greater trochanter, or by the pelvis being caught in a vise or similar mechanism. They are all crushing injuries and represent *compression* fractures of the femoral neck.

FIG. 18

Anteroposterior view of ununited adduction fracture of the femoral neck. *A:* Conelike proximal fragment consists of the terminal laminae of the internal weight-bearing system.

The fractures in which a normal internal weight-bearing system is present comprise all abduction and "intermedial" fractures (those with marked recurvation at the site of fracture) and many adduction fractures, to employ the sound classification of Per Linton.

The specimen at the authors' disposal with a healed fracture showed that the new-bone formation proceeded from the internal weight-bearing system. The system increased in volume and extent, crossed the cavity of the neck, grew into the cortical shell, and, forming what appeared to be cortical bone, penetrated into the head (Fig. 16). A portion of the capsule was engulfed by the new bone. The remnants of the capsule proved histologically to consist of fibrous tissue, leukocytes, and a large number of histiocytes.

The specimens with non-union had all had adduction fractures. Only insignificant remnants of the internal weight-bearing system could be found in them, even in the two recent specimens. Thorough study revealed that the resorption of the internal weight-bearing system was not a simple disappearance of the structure. From the site of its distal anchorage, below the region of the lesser trochanter, the entire distal portion of the internal weight-bearing system had been transformed into cortical bone. The posterior aspect of the cortex became twice or more its original thickness (Figs. 17-A and 17-B).

The separation takes place at the cervicocapital juncture, as is typical of this type of fracture of the femur; the separation line of the cortical shell and that of the internal weight-bearing system are in the same plane. The proximal fragment of the internal weight-bearing system is a conelike structure which still contains many laminae (Fig. 18).

Consideration was given the question of why the conversion of the internal weight-bearing system into cortical bone should affect only the distal portion of the system, and why the central portion should break atraumatically, as it were. The conversion of the spongy laminae into cortical bone takes its origin from the cortical shell. Wherever the internal weight-bearing system is closely apposed to the cortical shell, this conversion may be an easy process under certain pathological conditions preceding fracture (see Comment). The proximal portion of the internal weight-bearing system, however, branches off

from the cortical shell to enter the core of the head in fanlike shape. After this deviation it does not abut cortical bone, but is surrounded on all sides by bone marrow.

Apparently at the point where the cortical shell ceases to support the internal weight-bearing system, a slow resorption takes place and the pathological separation occurs. This process may be preceded by the conversion of the bone marrow, surrounding the capital and subcapital laminae, into fatty marrow, while the rest of the system remains embedded in red marrow, as mentioned before (Fig. 10). Nowhere do spongy trajectories or laminae form the continuation of cortical bone; only the inner layers of cortical bone are formed everywhere by spongy tissue. This could hardly be the case with the internal weight-bearing system. After the marrow deteriorates, the proximal end of the internal weight-bearing system loses its blood supply and separates, because it has become the continuation of a system subject to a different mode of nutrition. Although the spongy structures draw their blood supply mainly from the bone marrow itself, the cortical shell is supplied chiefly by arteries of the capsule and of the periosteum. After the bone marrow has disintegrated, the distal end of the internal weight-bearing system, converted into cortical bone, is supplied with blood, much as occurs in the rest of the cortical shell of the neck. However, no adequate source of blood is present to supply the proximal spongy laminae; and, after the reduction in their number and strength or after change in the character of the marrow surrounding them, separation occurs.

Thickening of the posterior cortical shell is one of the main roentgenographic signs preceding and accompanying adduction fractures of the aged. Other signs of equal significance are the following: The proximal fragment of the internal weight-bearing system contains only a few more or less distinct laminae; the spaces between the laminae are large; and the proximal fragment ends in a short cone, the end of which is a sharp point. The site of separation of the internal weight-bearing system and that of the cortical shell coincide; both are to be found at the capitocervical juncture (Fig. 18). This is in contrast to the findings in so-called abduction fractures.

The trauma preceding the adduction fracture may be a fall on the region of the greater trochanter, but this is not necessarily the case. Frequently, especially in old people, such normal functions as sitting down, getting up, turning in bed, or simple slipping of the feet are the "injuries" preceding the fracture. Frequently one gains the impression that the fracture of the cortical shell occurred after the patient's fall, and that the patient fell at the instant when the proximal portion of the internal weight-bearing system had separated from its distal portion. The adduction fractures showing the signs enumerated, especially in the aged, appear to be closely related to pathological fractures. In reality, they represent a definite form of subcapital separation. Thus as regards etiology, there are two distinct types of fractures of the neck of the femur:

1. *Compression fractures* of the femoral neck, comprising all cases showing a healthy internal weight-bearing system, and consisting of abduction, intermedial, and also of adduction fractures.

2. *Subcapital separations* with subsequent fracture of the cortical shell, comprising only adduction fractures.

The prognosis and treatment of the two types are fundamentally different. The compression fractures may heal in from four to eight weeks, if the proximal and distal fragments of the internal weight-bearing system are in apposition and if care is taken in their fixation. A plaster bandage or Russell traction may be used, but with Russell traction no more than four pounds should be applied, lest the fragments should separate. Nailing will hasten union and render the fixation safe, but the relatively high number of cases with necrosis and deformity after nailing is probably due to the procedure.

The subcapital separations, in order to unite, need such treatment as is capable of either replacement of the internal weight-bearing system or of its stimulation by biological, mechanical, or perhaps chemical means.

Mechanical means are employed in the procedures of nailing or drilling. Both seem to be able to act on the remnants of the internal weight-bearing system in such a manner that the cells revive and multiply, forming new bone. In addition, in several specimens it was found that new-bone production started from the remnants of the internal weight-bearing system,—not enough to unite the fragments, but sufficient to cover the distal fragment with a layer of new bone. This newly formed lamina seals off the distal fragment from the proximal fragment, excluding any possibility of spontaneous union (Figs. 17-A and 17-B). In this respect the drilling, with its holes, and the nailing, with its large channel breaking through the separating lamina between the fragments, may induce the spongy laminae of the internal weight-bearing system to grow into the proximal fragment. It should be emphasized, however, that no method has even a fair chance of producing union which disregards the fact that only the conelike end of the proximal fragment is capable of adequate new-bone formation, as it contains the terminal portion of the laminar internal weight-bearing system. Consequently, the proximal fragment has to be brought into contact with the remnants of the internal weight-bearing system in the distal fragment, or, if the system be missing and replaced, with the spongy surface of the graft. This contact is the main sign of good reduction.

Naturally an attempt has been made to replace surgically the internal weight-bearing system in fractures of the neck of the femur. The problem was to find and insert into the neck a bony structure sufficiently hard to maintain reduction, but at the same time consisting of bone, at least similar to that to be replaced, and capable of adequate new-bone formation in a relatively short time. As the authors' studies had shown that union of the cortical shell in fractures of the neck of the femur proceeds mainly from the internal weight-bearing system (Fig. 16), the former structure could not be relied upon as the means of bony union in the absence of a rich source of bone repair within its confines.

The spongy structures of iliac bone are best suited for such a procedure but, being too soft, they would hardly maintain reduction. Therefore, the cortex of the femur just distal to the greater trochanter was used, a structure employed by Matti in his experiments to prove the superiority of spongy bone for grafting purposes. After long experimentation, from fifteen to twenty minute holes were drilled into the graft before it was removed. This allowed the spongy surface of the graft to grow through the drill holes, and the host surface to use the same channels to engulf the graft, thus uniting with a speed of which only the spongy laminae are capable. The graft is now inserted frontally, with its broad periosteal surface facing the anterior wall of the neck.

The graft was named the perforated or sieve graft. As it was applied closely underneath the cortical shell, resting, as it were, on the inferior surface of the neck, in analogy of the onlay and inlay grafts, it was called a "sublay graft". Hence its name is "*perforated* (or sieve) *sublay graft*".

The technique and the results of the method will be reported soon.

COMMENT

The fast healing of abduction fractures cannot be explained solely on the basis of the angle between the fragments and the vertical plane, as claimed by Pauwels. Such fragments do not become displaced, apart from the angle, for the following reasons: (1) because the internal weight-bearing system is similar to the bone in a greenstick fracture; (2) because no tensile stresses are present at the hip region; and (3) because the internal weight-bearing system heals so fast that by the time the patient starts weight-bearing, bone repair in the interior of the neck might have proceeded almost to complete union.

It also appears probable that the reason some fractures remain in the state of abduction fractures is that the internal weight-bearing system does not permit further displacement. Not the angle of separation, but the state of the internal weight-bearing system, is the chief factor. The problem of abduction fractures is biological rather than mechanical.

One of the purposes of this study has been to arrive at a biological explanation of abduction fractures.

By experimental testing, Kolodny found that, to produce a compression fracture of the femoral neck, an average of about 375 pounds are required; while Dixon found that to bring about a vertical break, from 1,800 to 2,500 pounds are required. This corresponds to a fall of 150 pounds of body weight from a height of twenty-eight feet. Therefore, it is conceivable that the neck of the femur may break when one falls on the side, crushing the femoral neck; but it is hardly conceivable that adduction fractures, especially of the aged, would occur as a result of the injury alone, when one takes into consideration the amount of impact required to produce it.

As to the cause of the transformation of the internal weight-bearing system into cortical bone in the distal part of the system, the work of David Greig might be referred to. According to this author: "Restrict the blood supply and bone undergoes consolidation, increased density, osteosclerosis". One is tempted to assume that arteriosclerosis of the marrow vessels, decreasing the blood supply of the structures depending upon them, may lead to both the deterioration of the laminar system and the deposition of a new cortical layer on the marrow surface of the cortical shell.

SUMMARY

Dissection and roentgenographic analysis of the upper portion of the shaft and neck of the femur revealed the presence of a highly independent laminar, bony system, from ten to twelve centimeters long, which begins from two to four centimeters below the lesser trochanter and ends in fanlike fashion at the cartilaginous plate of the head. This proved to be the internal weight-bearing system of the proximal portion of the femur.

This system undergoes slow resorption in its distal portion after middle age, but never disappears; and on the roentgenogram it can be seen throughout life from its distal to its proximal end. Microscopically, it consists of a great number of laminae and bone cells, and a rich endosteal lining. It resembles the spongy laminae of the iliac bone,—hence the speed with which it is capable of new-bone formation.

Mechanically, the internal weight-bearing system is a compression system, and during weight-bearing it is to be found almost in the vertical plane. The presence of tensile stresses is doubtful.

Preceding adduction fractures, the internal weight-bearing system is resorbed and replaced by cortical bone in its entire distal portion. Its proximal end remains spongy, with laminar character. The separation occurs at the site where the spongy proximal portion begins and the distal cortical portion ends.

In abduction fractures, the internal weight-bearing system suffers only trauma, but otherwise it is healthy and strong. This explains the rapid healing of such fractures.

On the basis of the anatomy and pathology of the femoral neck, two types of fracture may be distinguished: (1) compression fractures, comprising the abduction, intermedial, and adduction fractures; and (2) subcapital separations, represented by most fractures of the aged. The prognosis of the compression fractures is good, if the fragments are kept in good apposition and fixation in plaster, in Russell traction, or by nailing.

For the treatment of the adduction fractures, a method with a perforated (sieve) sublay graft has been developed.

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HOMOGRAFTS IN ORTHOPAEDIC SURGERY *

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A fairly large group of children and adolescents need surgery for various orthopaedic conditions in which excessive amounts of bone are required for grafting. A vast quantity of suitable bone may be secured from the relatives of the patient. Good results may be expected from the use of homografts; the danger of shock is less, and there is less disfigurement of the patient.

Wade reported successful grafting of bone from another individual in an ununited fracture of a long bone nearly thirty-five years ago. Recently, homografting has been practised quite extensively in battle casualties, and the satisfactory results obtained seem to warrant its wider use. Albee, Armstrong, Meyerding, and others admitted the value of homografts long ago, but expressed preference for autogenous grafts. Time and experience have proved the superiority of the autogenous graft; but there are many instances, especially in children and adolescents, where enough autogenous bone cannot be secured. In children, the tibia is often too small, and sufficient bone cannot be removed without danger of injuring the epiphyseal plates. The quality or strength of the patient's bone (whether tibia or ilium) may be inadequate. The additional shock from the removal of the graft is always to be considered.

For these and other reasons, surgeons have searched for many years for substitutes for autogenous bone. Beef bone, ivory, and even cow horn have been used, but have gradually been discarded. Os purum, os novum, and boiled bone have been used successfully by Orell. Os purum has been used quite extensively in this country by Goff, who believes that it has a definite place in bone surgery and is a satisfactory material for grafting. His work shows that os purum seems to be tolerated by the host as well as autogenous bone, but at the present time there is little or no os purum available in this country. Inclan and others have used preserved bone in patients in whom the operative risk was high, when it was inadvisable to use autogenous bone because of the extreme difficulty of acquiring it, or when the osteogenic power of the bone which was available was poor.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 28, 1947.

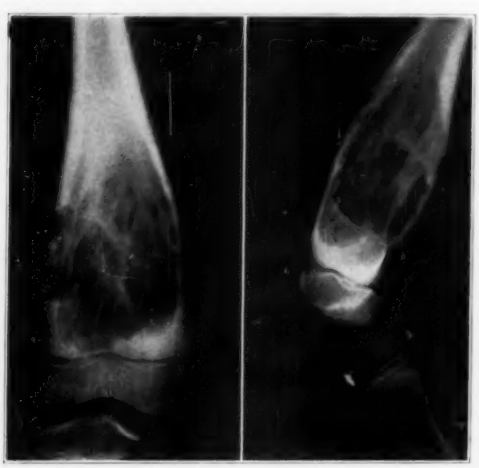

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. The patient was a boy of seven years, with a preoperative diagnosis of giant-cell tumor of the femur. The cavity was curetted and filled with autogenous chip grafts from the tibia.
Fig. 1-B: Seven months after operation. The grafts are taking.

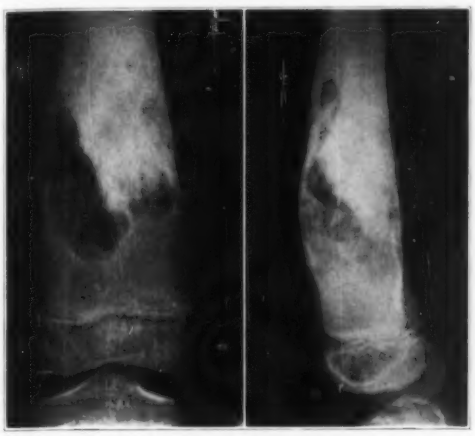

FIG. 1-C

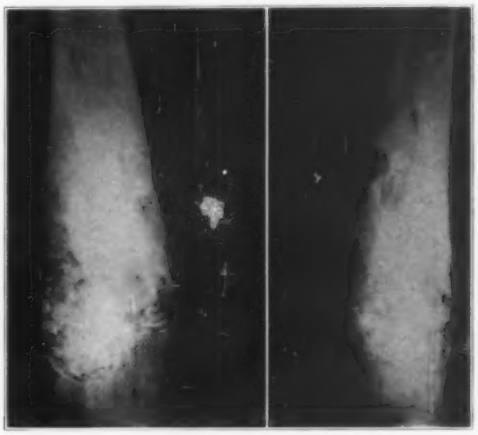

FIG. 1-D

Fig. 1-C: Twenty-one months after operation. Partial recurrence after the use of autogenous chip grafts.

Fig. 1-D: Two months after second operation. Cavity was curetted and filled with chip grafts from the father.

Fig 1-E: Four months after second operation. Chip grafts from father are taking well.

FIG. 1-E

World War II has stimulated interest in preserved bone grafts; and, at present, work is progressing in some clinics to establish banks of preserved bone. As soon as the danger of infection can be eliminated, the use of preserved grafts will undoubtedly find a place in orthopaedic surgery. Boiled grafts and autoclaved grafts have long been used when grafts became contaminated in the operating room, and good results have been reported.

Objections to the use of homografts have been made by some authors, who fear transmission of disease, incompatability of blood and Rh factor, or differences in sera. Boyd, Ghormley, and others who have used homografts more extensively find no need even for matching blood, because very little blood is transplanted with the bone. Because of these and other reasons, homografts may not have had the wide application they deserve. The objections to homografting do not seem to be supported by clinical evidence. Theoretically, the closer the relationship of the donor to the recipient, the better the chances of success.

In the accompanying examples of homografting, all of the grafts have been taken from male relatives of the patient and are syngenesioplastic grafts. The blood was matched in every case, but this seems unnecessary. Syngenesioplastic grafts are easily obtained in private practice from the father or brother, who is usually willing to donate bone from the tibia or ilium. Most brothers consider the contributions little more than blood transfusions. Syngenesioplastic chip grafts of cortical bone were used in each of the cases presented. More resently, H grafts and chip homografts of cancellous bone have been employed, and the results promise to be equally good.

In benign, destructive bone tumors in children, frequently enough bone cannot be obtained from the patient himself, especially if the tumor recurs and more bone is needed. The opposite tibia can be used, but further recurrence may suggest the need of telescoping the bone or of looking elsewhere for osteogenic material. In such cases, the father can donate the necessary bone (Figs. 1-A, 1-B, 1-C, 1-D, and 1-E).

In severe destruction by benign bone tumors, it may be technically impossible to excise the tumor thoroughly. If the tumor recurs, amputation or telescoping may be avoided by filling the new cavity with bone from a brother; and, should further extension

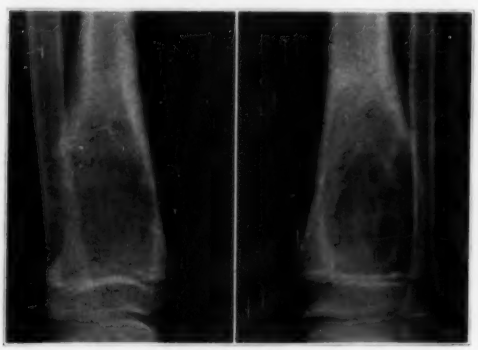

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 2. The patient was a girl, eight years of age, with a clinical diagnosis of hemorrhagic cyst of the tibia. Note relationship to epiphyseal line.

Fig. 2-B: Five months after operation. Cavity was curetted and filled with autogenous chip grafts from opposite tibia.

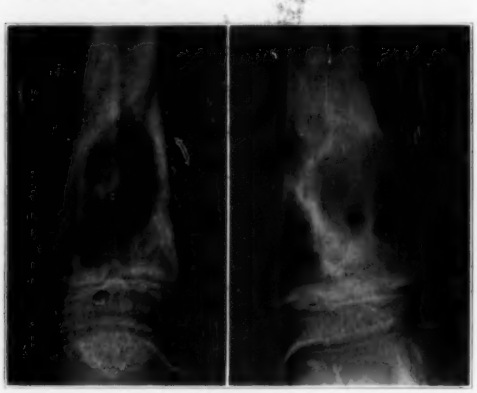

FIG. 2-C

FIG. 2-D

Fig. 2-C: Ten months after operation. Partial recurrence took place following the use of autogenous chip grafts.

Fig. 2-D: Two months after second operation. Cavity was curetted and filled with chip grafts from patient's brother, aged seventeen.

FIG. 2-E

FIG. 2-F

Fig. 2-E: Four months after second operation. Grafts are taking. Note that growth is continuing.

Fig. 2-F: Shows beginning recurrence of tumor proximally, eleven months after homografts.

FIG. 2-G

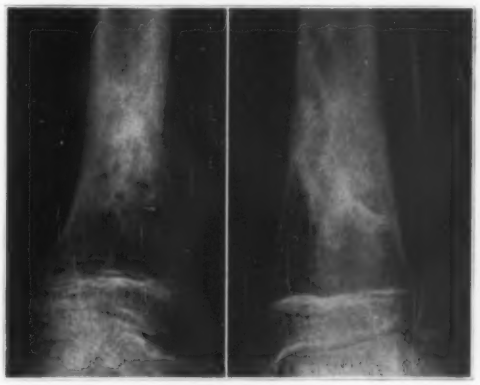

FIG. 2-H

Fig. 2-G: Two weeks after third operation. Cavity was again curetted and filled with chip grafts from another brother, aged sixteen years.
Fig. 2-H: Two years after third operation.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. A male infant, one month old, showed evidence of congenital pseudarthrosis of the tibia. Roentgenogram, taken at the age of seven months, shows subperiosteal fracture.
Fig. 3-B: Two years after spontaneous fracture had been treated by plaster-cast immobilization.

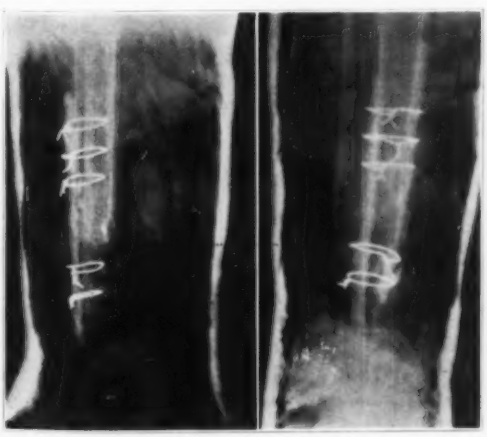

FIG. 3-C

FIG. 3-D

Fig. 3-C: Dual grafts from father have been applied, by the method of Boyd.
Fig. 3-D: After six months, dual grafts are part of host. Fracture has healed.

FIG. 3-E

FIG. 3-F

Fig. 3-E: Refracture occurred eleven months later.
Fig. 3-F: Roentgenographic appearance nine months after refracture.

occur, bone growth and apparent cure may be possible by the use of grafts from a second brother (Figs. 2-A to 2-H, inclusive).

In pseudarthrosis of the tibia, Boyd reported that: "Autogenous grafts are preferred, but in children it is difficult to secure sufficient bone for a good onlay graft, and impossible to obtain enough for a dual graft". This is verified by the author's experience. Although dual grafts from the father may take well and may become a part of the host, such grafting will not prevent refracture in pseudarthrosis any better than autogenous grafting will; but grafting may be repeated at a later date, if necessary (Figs. 3-A to 3-F, inclusive).

In structural scoliosis, spondylolysis, and spondylolisthesis, especially in young girls, a psychological factor frequently affects treatment. Many of these young patients resent operative scars on legs or hips, and often, to avoid the scars, prevail upon their families to abandon the operation. In such instances, the homograft solves the problem. Brothers and other male relatives are often proud to contribute bone. Although autogenous grafts are considered to be better, there is a definite place for homografts.

CONCLUSIONS

1. When a sufficient amount of bone, or bone of proper quality, cannot be easily and safely obtained from the patient, the surgeon should consider syngenesioplastic grafts or homografts.

2. The results with homografts—especially syngenesioplastic grafts—warrant wider use in certain conditions.

3. To date, there is no factual evidence to prove that homografting, in selected cases, is not a sound surgical procedure.

4. Greater experience with homografts may advance the art of orthopaedic surgery.

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DISCUSSION

DR. RUFUS H. ALLDREDGE, NEW ORLEANS, LOUISIANA: Orthopaedic surgeons everywhere will be indebted to Dr. Henry for calling attention to such a valuable, and heretofore rarely used, method of bone-grafting. This is an important subject, and there is no doubt that much more will be heard about the use of homogenous bone in the near future.

Dr. Henry has used homogenous bone chips in most of his patients, because of the nature of the cases with which he had to deal. He has shown that they have served the purpose well. This is important, because it demonstrates that homogenous bone chips may be used as successfully as massive grafts of cortical bone.

My own experience with homogenous bone grafts has been limited to the use of full-thickness cortical grafts and entire sections of the fibula, alone or in combination. This discussion will, therefore, be limited to the use of homogenous grafts of this type.

Dr. Calvin K. Terwilliger and I, while in the Army, performed fifteen homogenous bone-graft operations on soldiers between March 1945 and March 1946. All of the patients had had at least one amputation, and two were double amputees. All had been wounded in action, and all grafts except one were done at sites where compound fractures had indicated the need for grafting. In eleven of the fifteen cases, loss of substance of the shaft of the bone was present, in addition to non-union. Two of the grafts were employed to extend the length of the humerus, in an effort to make possible the use of a prosthesis. Four others were used for non-union and loss of substance in the bones of amputated extremities, to prevent reamputation at higher levels.

The bones grafted were: humerus, five; ulna, four; radius, one; femur, two; and tibia, three. An entire section of the fibula was used alone as an intramedullary graft in four cases. The intramedullary fibular graft was reinforced with a massive full-thickness cortical graft in three cases. A massive cortical onlay graft was used alone in seven cases, and a double onlay graft in one.

The bone in each case was removed from the donor immediately before it was used on the recipient. Cross matching or grouping of the blood was not done. The donor was examined carefully for syphilis and other serious diseases. The bone used was taken from amputation stumps below the knee; these were too long and would have been reamputated anyway.

In ten of the fifteen cases thus grafted with bone from another patient, the results were classed as excellent in every respect when the patient was last seen, a year or more later. Three other patients obtained good healing, but, due to accident or undue carelessness and failure to cooperate, fracture of the grafts occurred after healing had taken place. Low-grade infections with drainage developed in the other two patients, and the grafts were lost. These two were the only complete failures.

In no case could results short of perfection be attributed to the use of homogenous bone. In fact, the results were all that could have been expected from autogenous bone grafts.

The implications of the successful use of homogenous bone are far-reaching. This is probably only the beginning of renewed interest in, and full appreciation of the value of, homogenous bone. Further use of stored bone will be necessary to determine finally whether a bone donor, in the ordinary sense, will be necessary in the future in cases in which homogenous bone is to be used.

DR. J. S. SPEED, MEMPHIS, TENNESSEE: Dr. Henry has showed us many interesting uses of homogenous grafts. Dr. Alldredge, in his discussion, shows the advantages and value of this bone as a means of bridging defects and for non-union. The advantages to the patient, when homogenous bone is used, are obvious.

The use of refrigerated bone, which has not been available before, opens up a vast field in reconstructive surgery. With the use of refrigerated bone and with the ability to preserve this bone in a more or less vital state, we are able to obviate many of the disadvantages that go with massive bone surgery Theoretically, there should be no objection to the use of refrigerated bone. Our experience with it has coincided exactly with Dr. Henry's. Our conclusions with regard to homogenous bone, as compared with autogenous bone, are that there is very little difference. Perhaps there is more tendency to absorption, and the homogenous bone resists infection less; otherwise they are the same.

DR. ALBERTO INCLAN, HAVANA, CUBA: We have been using preserved bone grafts for ten years, and we have had almost 100 cases. We have been unable to study the possibilities of frozen bone because, on account of the War, we were deprived of a freezing machine; but we are already using refrigerated bone, kept at

2 degrees centigrade in an ordinary refrigerator. We are very pleased with its use in cases of spine fusion, where it helps to avoid shock and eliminates mortality, as Dr. Henry has mentioned. We have used a great deal of refrigerated bone for bone-grafting in fractures of the neck of the femur.

When using homogenous bone, we have taken it from the donor under local anaesthesia and kept it in the refrigerator for one or two weeks, until we were ready to perform the second operation on the hip. In large defects of bone, when no autogenous bone was available, we have been able to use cancellous bone.

I am sorry I did not know this paper was on the program, so that I might have reviewed my cases beforehand.

DR. ALAN DEFOREST SMITH, NEW YORK, N. Y.: My interest in this subject began about twenty years ago, when a patient, eleven years old, had fragilitas ossium and an ununited fracture of the shaft of each femur in the upper third, with marked deformity. It was obviously impossible to get bone from the patient. The child's mother was admitted to the hospital, and I used a massive graft from one of her tibiae, which united well. Later I did the same thing on the other hip. Subsequently, the patient was able to walk, and has had no further fractures.

Later I did a similar operation in a case of fragilitas ossium, using a relative (the mother's mother). We have used homogenous bone in cavities left by cysts and tumors, and in congenital pseudarthrosis of the hip. During the last year we have had a bone bank at the New York Orthopaedic Hospital, with a freezer which is placed at minus 25 degrees centigrade. We have used the refrigerated bone in 100 cases and found it very helpful; there have been no bad results, and all were what we would expect from the use of fresh autogenous bone.

These banks are being established all over the country. Dr. Alldredge told me that he had the first one at a British General Hospital during World War II. With homogenous bone, one should be careful to rule out infection. We do not use any bone for two weeks, and we are careful to eliminate syphilis and malaria. I do not think blood typing is necessary.

Dr. Henry has made a very important contribution and, with the possibility of preserving the bone by refrigeration, this method will have a much wider application than in the past.

DR. J. R. MOORE, PHILADELPHIA, PENNSYLVANIA: For the past six years, it has been our custom to employ a graft of os novum in the treatment of pseudarthrosis, particularly congenital pseudarthrosis. A graft of adequate length is removed subperiosteally from the ilium or the tibia with the motor saw, lifted from its bed to make sure it is entirely free, and then replaced. The periosteum is closed, along with the subcutaneous tissue and skin, and the graft is left in place for eighteen days in a child and for four weeks in an adult. It is then removed and used as a self-sustaining bone graft. Fixation is obtained by double pins above and below in the fracture fragments, combined with plaster-of-Paris. These delayed grafts show microscopic evidence of new-bone formation about their surfaces, and there has been a marked increase in phosphatase over the normal at the end of the eighteen to twenty-eight days. The regenerative power of these grafts appears remarkable. The use of homografts in a series of cases of congenital pseudarthrosis with a four-year follow-up will be reported shortly.

Dr. Henry's excellent presentation brings out clearly the possibilities that may be expected from the use of homografts. Their usefulness should be kept in mind constantly.

DR. MYRON O. HENRY (closing): I think you will find it much easier to get donors to contribute bone from the ilium. The cases I have presented were done five, six, and seven years before Dr. Phemister told us about cancellous bone. Cancellous bone from the posterior portion of the ilium has the advantage that the donor does all the bleeding and not the recipient, which reduces the danger of shock.

THE MECHANISM OF INJURY AND THE DISTRIBUTION OF THREE THOUSAND FRACTURES AND DISLOCATIONS CAUSED BY PARACHUTE JUMPING

BY MAJOR ROY CICCONE AND CAPTAIN ROBERT M. RICHMAN

Medical Corps, Army of the United States

During the recent war years, considerable surgical interest has centered on the injuries resulting from parachute jumping. Now that the military-training program has subsided almost to peacetime levels, it is possible to supplement the earlier papers on parachute injuries [10, 13, 14, 21, 22] with a more definitive report, covering more than 600,000 parachute jumps conducted by the Airborne School at Fort Benning, Georgia. The casualties incident to this training were undeniably heavy; over 3,000 men were sent to the hospital with fractures and major dislocations, while the sprains, contusions, and lesser soft-tissue injuries were numerous almost beyond reckoning. A complete catalogue of the injuries would include such a confusing variety of lesions, some of them extremely bizarre, that the list would be merely a statistical curiosity. In order to achieve a proper perspective, therefore, this discussion will be devoted only to the more typical, recurrent patterns of injury encountered in parachute jumping, with particular attention to the traumatic mechanisms involved. The survey was facilitated by the fact that all orthopaedic casualties from the Airborne School were sent to the hospital and treated under the personal observation of the authors.

The anatomical distribution of these fractures and major soft-tissue injuries is summarized in Tables I and II. As one would expect, the injuries showed a strong predilection for weight-bearing structures; the foot and ankle, leg, femur, and spine together account for 90 per cent. of the series. The relative frequency of certain injuries, however, is different from that encountered in civilian orthopaedic practice. The series includes few fractures of the calcaneus and of the distal end of the radius, for example, although traditionally they are both associated with the trauma of falling. Fractures of the posterior tibial margin and multiple metatarsal fractures, on the other hand, are disproportionately prevalent among parachutists. The reasons for this unusual distribution of injuries become apparent when one considers their special traumatic hazards.

FIG. 1

Photograph of a parachutist descending correctly. Note the semiflexed, springy attitude of the legs, so that he lands on his toes rather than on the heels, and absorbs the impact against the elastic resistance of the muscles. (*Photograph by U. S. Army Air Corps.*)

TABLE I

ANATOMICAL DISTRIBUTION OF 2,709 FRACTURES DUE TO PARACHUTE JUMPING

Location	Number		Per cent.
Lower extremity		2,331	86.0
Ankle	1,462		
External malleolus alone	635		
Posterior tibial margin alone	319		
External malleolus plus posterior tibial margin	218		
Bimalleolar fracture with fracture of the posterior margin of the tibia (the "trimalleolar" fracture of Henderson [12])	112		
Internal malleolus alone	99		
Bimalleolar	60		
Others	19		
Metatarsals (total)	385		
Single metatarsal	90 cases		
Multiple metatarsals	103 cases		
Tarsals	186		
Talus	54		
Navicular	49		
Calcaneus	40		
Cuboid	27		
Cuneiform bones	4		
Phalanges	12		
Tibia and fibula (shafts)	251		
Tibia plus fibula	125		
Tibia alone	27		
Fibula alone	78		
Tibial plateau (including tibial spines)	21		
Femur	36		
Patella	11		
Trunk		206	7.6
Vertebrae (total)	168		
Single vertebrae	80 cases		
Multiple vertebrae	41 cases		
Pelvis	22		
Transverse processes of vertebrae	8		
Ribs	8		
Upper extremity		156	5.8
Humerus	38		
Shaft	16		
Greater tuberosity	22		
Clavicle	35		
Scapula	6		
Olecranon	5		
Radius (total)	26		
Head	11		
Shaft	5		
Colles's type	10		
Carpals and metacarpals	26		
Phalanges	20		
Others		16	0.6
Total		2,709	100.0

Most parachute training in this country has been conducted from the C-47 airplane, the military counterpart of the familiar DC-3 commercial transport. The sequence of events in a typical parachute jump is as follows: When the plane approaches the drop

TABLE II

MAJOR SOFT-TISSUE INJURIES DUE TO PARACHUTE JUMPING

Cerebral concussion		110
Tears of knee ligament		93
Abduction instability	88	
Adduction instability	4	
Complete dislocation (anterior)	1	
Shoulder dislocations		39
Acromioclavicular separations		23
Elbow dislocations		9
Dislocated head of fibula		8
Separations of symphysis pubis		8
Metatarsophalangeal dislocations		8
Metacarpophalangeal dislocations		3
Carpometacarpal dislocations		2
Tears of biceps muscle		2
Hip dislocation		1
Total		306

zone, it slows down to an air speed of 110 miles per hour; the jumpers stand ready; and, at a signal from the jumpmaster, they leap feet first out the door, in rapid succession (Fig. 16). As each man clears the plane, his parachute pack is ripped open automatically by a static line attached to the plane; the silken canopy unfolds, catches the air, and checks his fall with a violent but reassuring jar. This is known as the "opening shock". The jumper then floats down-wind, controlling his direction and drift to some extent by manipulating the "risers" overhead. He holds feet together, toes pointed downward, knees and hips slightly flexed, as shown in Figure 1. The muscles are not tense, but are alert to absorb the shock at the moment of impact. The parachutist is taught to land on his toes, facing down-wind so that the horizontal momentum carries him forward rather than backward. He makes no attempt to remain standing, but twists to one side like a tumbler and cushions his fall by rolling onto the muscular areas of the calf, thigh, buttocks, and back. He then throws off the parachute harness and is ready for action.

Naturally, a great deal of preliminary training is necessary in order to teach the novice how to bail out correctly, control his descent, and land without injury. A freezing fear of heights is instinctive in the untrained individual; he either lands stiff-legged and suffers a fractured heel, or lunges forward on outstretched hands and pays for this mistake with a fractured wrist. Parachutists are specifically trained to avoid these errors. All phases of the actual parachute jump, from the opening shock to the landing impact, are simulated by special apparatus, so that ultimately the smooth follow-through to a cushioned-landing fall becomes an automatic response.

Despite the most thorough training, however, there are certain inescapable hazards beyond human control, which magnify the risks of parachute jumping. Chief among these is excessive wind velocity. Jumping on a windy day is somewhat like leaping from the top of a moving train; besides the force of gravity, there is an additional horizontal drift that greatly increases the shock of landing. Furthermore, the wind invariably sets up "oscillation", so that the jumper swings back and forth beneath the parachute like a pendulum and may strike the ground from an unpredictable and dangerous angle. Occasionally, jumpers drift together and become entangled, collapsing each other's parachute and falling the last fifty feet or so with great violence. Tree landings, rough terrain, and the opening shock also take their toll of injuries. Even with all of these "occupational" hazards, it is remarkable that the rate of over-all injury at the Airborne School during the past two years has consistently been less than one casualty per hundred jumps[14]; and

TABLE III

INJURIES DUE TO EXTERNAL ROTATION PLUS LANDING THRUST

Location	Injury
Foot	Dorsal dislocation of the toes
	Metatarsal fractures, multiple or single
	Compression fractures of mid-tarsal bones
Ankle	Oblique fracture of lateral malleolus
	Vertical fracture of posterior tibial margin
	Combined fracture of lateral malleolus and posterior tibial margin
	Diastasis of tibiofibular syndesmosis
	Bimalleolar fracture with fracture of the posterior margin of the tibia at the ankle
	Bimalleolar fracture
	Solitary fracture of internal malleolus
	Various combinations of malleolar fractures with leg fractures
Leg and knee	Spiral fracture of shaft of tibia
	Oblique fracture of shaft of neck of fibula
	Combined spiral fractures of tibia and fibula
	Dislocated head of fibula
	Tear of medial meniscus of knee
	Tear of medial collateral ligament of knee
Thigh	Spiral fractures of shaft of femur
	Fracture of neck of femur

even this low figure is declining steadily, due to constantly improved training techniques and safety precautions.

When one reviews the injuries listed in Tables I and II in the light of the clinical findings and history, it becomes evident that almost all of them can be attributed to only four recurrent traumatic mechanisms: (1) torsion plus "landing thrust", (2) backward landing, (3) opening shock, and (4) violent vertical fall. These, with minor variations, are the main causes of injury in parachute jumping. It is proposed to explain these mechanisms, discuss the underlying traumatic stresses in detail, and illustrate the specific lesions for which each is responsible.

It should be admitted at the outset that the clinical evidence regarding traumatic stresses is largely circumstantial. Obviously, there is no opportunity to observe the accidents at first hand under controlled conditions. Also, the patients' histories are notoriously inaccurate, and usually too vague to furnish any reliable information about the nature of the trauma. Some investigators have attempted to analyze traumatic stresses on the cadaver, but the results of their experiments are not entirely applicable, since it is impossible in the laboratory to duplicate all the complex muscle leverages, and the impact of the actual landing. In the absence of more direct evidence, therefore, one is forced to rely upon clinical observations and to deduce the etiological trauma from the injury. Sometimes this is easy; the gross distortion of the limb may identify the stress. Soft-tissue swelling is also suggestive, especially early after injury, before it has had time to diffuse. The roentgenograms are particularly valuable; the direction of fracture lines—oblique, spiral, or transverse—the displacement of fragments, impaction, comminution, chip fragments, and many other signs, all characterize the antecedent stress. The most characteristic and conclusive proof of the mechanism, however, is elicited in the course of treatment. At this time, one can test the fragments under anaesthesia, first carefully exaggerating the distortion and then reducing it, and in this way determine the forces which were

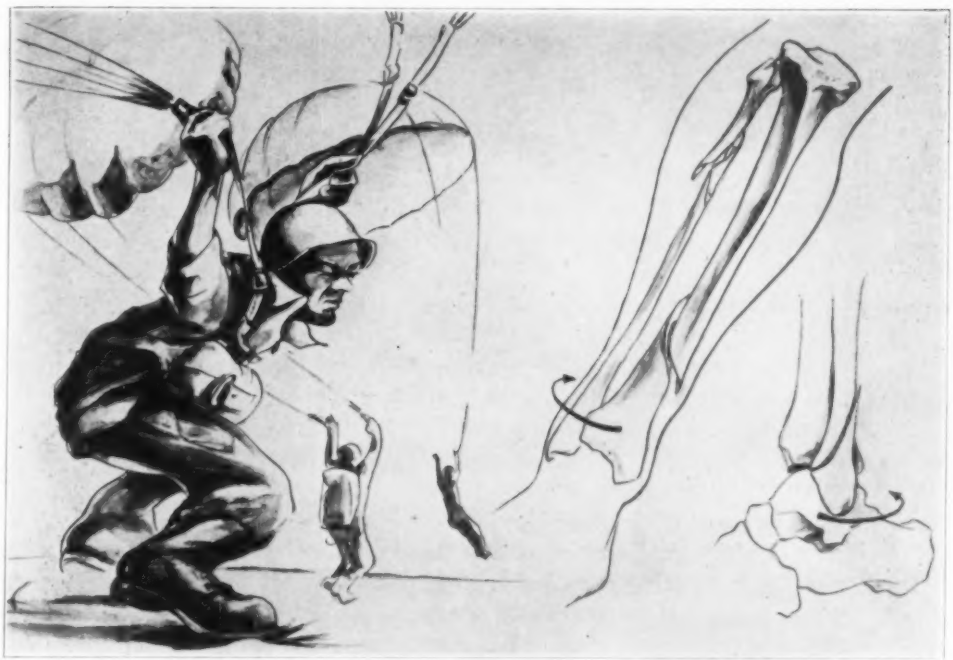

FIG. 2

Shows the mechanism of external-torsion fractures and two classical fractures. The great majority of parachute fractures are of the external rotation or abduction type.

responsible for the injury. Admittedly, the method has its limitations, but by integrating all the bits of evidence outlined, it is possible to recognize the underlying stresses of each of the traumatic mechanisms from the injuries they produce.

TORSION PLUS "LANDING THRUST"

This is by far the most common mechanism of injury, since it represents an exaggeration of the forces normally encountered in parachute landing. As explained earlier, the parachutist descends with a downward and forward momentum, gravity and wind drift contributing, respectively, the main vertical and horizontal components. At the moment he strikes the ground, there is generated against his feet an upward and backward reactive thrust—which we call the "landing thrust"—and, in addition, various torsional stresses, due to uneven ground and the ever-present oscillation. Under normal conditions, these stresses are not violent enough to cause injury; the impact is transmitted through the foot and ankle and dissipated against the elastic resistance of the muscles and supporting structures. When the same landing stresses are exaggerated by unfavorable jumping conditions, however, they may exceed the physical tolerance of the body, disrupt the supporting structures, and produce a wide variety of fractures, sprains, and dislocations (Fig. 2).

In the list of lesions, external-torsion injuries far outnumber those due to internal torsion. Without a digression into detailed functional anatomy, it would appear that the supporting structures are more yielding in the direction of internal rotation, whereas they are more rigid and consequently more vulnerable under the stress of external rotation. This is not an original observation. Ashhurst and Bromer have emphasized the statistical predominance of external-rotation injuries in their scholarly and well-documented study of ankle fractures. On the basis of our large series of injuries, it is proposed to extend Ashhurst and Bromer's conclusions and to show how external rotation, in combination with varying degrees of landing thrust, is responsible for a chain of injuries not only involving

the ankle, but also extending the entire length of the lower extremity from the toes to the hip. These injuries differ widely in pattern, as well as location, yet all are related by a common denominator, the same etiological mechanism. Some of the more typical injuries are listed in Table III.

Naturally, the specific lesion in each case depends upon the relative intensity of the traumatic stresses. A predominant landing thrust, for example, would crush the midtarsal bones, or drive the talus posteriorly in the ankle mortise and split off the posterior tibial margin. Predominant torsion stress, on the other hand, would be likely to rupture the tibiofibular ligaments, fracture the distal end of the fibula, or cause a spiral fracture of the shafts of both tibia and fibula. Theoretically, one could postulate infinite combinations and permutations of the traumatic stresses, and hence an unlimited variety of lesions; but fortunately, the problem is simplified by the fact that the statistical distribution of injuries favors certain recurrent clinical patterns—"classical" injuries, so to speak—around which this discussion will center.

External-Rotation Injuries

The oblique fracture of the distal end of the fibula has long been recognized as the prototype of this mechanism of injury. Its historical background and varied interpretation have been admirably described by Ashhurst and Bromer. It is an extremely common parachute injury; alone and in combination with other lesions, it is found in more than two-thirds of all our fractured ankles. The lesion is seen in Figure 3 as an oblique crack, extending from the anterior border of the lateral malleolus upward and backward across the tibiofibular syndesmosis to the posterior aspect of the shaft of the fibula. Often the fracture line is invisible in the standard anteroposterior roentgenogram, but it can be accentuated by reapplying the traumatic stress,—that is, by forcing the foot into external rotation. The foot then acts as a rigid lever, twisting the talus, which in turn crowds the

FIG. 3

FIG. 4

Fig. 3: The solitary low oblique fracture of the fibula is the most common parachute fracture and, indeed, the most common ankle fracture, regardless of the circumstances of injury. In this case, displacement is negligible, and the fracture line could barely be detected in the anteroposterior view.

Fig. 4: Avulsion chip fracture of the posterior process of the talus at the site of attachment of the posterior talofibular ligament. The fragment is suggestive of an os trigonum.

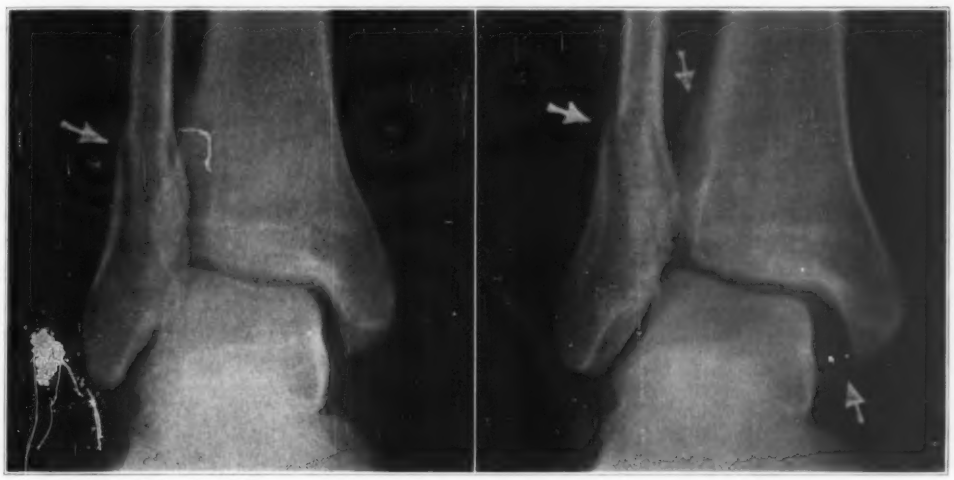

FIG. 5-A FIG. 5-B

An oblique fracture of the fibula, combined with tears of the deltoid and tibiofibular ligaments (as evidenced by the subperiosteal chip avulsed from the lateral border of the tibia). Fig. 5-A, taken with the foot in the standard neutral position, shows very little widening of the mortise. In Fig. 5-B, the foot is being externally rotated and abducted in order to demonstrate the latent diastasis.

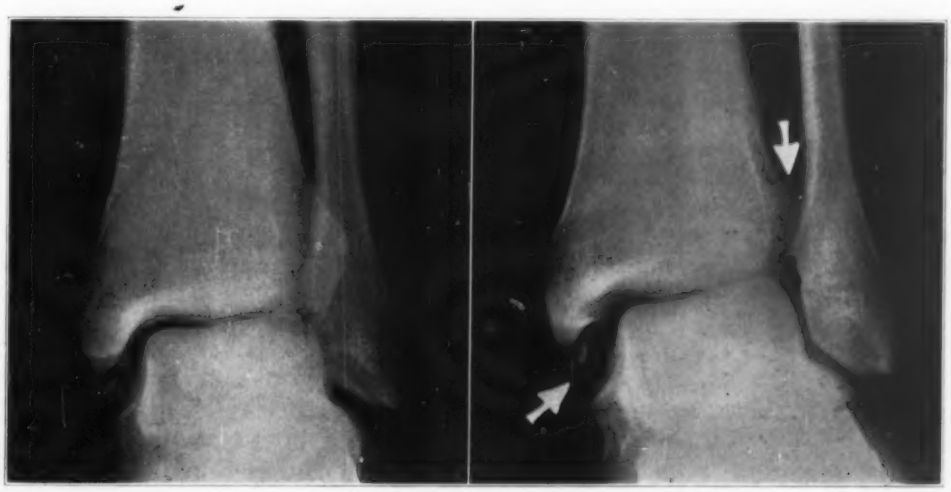

FIG. 6-A FIG. 6-B

Every sprained ankle should be tested for instability. In Fig. 6-A, this injury might be accepted as an ordinary "sprained ankle", with a chip avulsed from the medial malleolus. When the foot is forced into external rotation, however, the mortise gapes medially, and the tibiofibular diastasis becomes apparent. These are serious injuries, with a high incidence of "weak-ankle" disability and premature arthritic changes.

lateral malleolus laterally and simultaneously pulls it backward, through tension on the posterior talofibular ligament. The combined push-pull stress on the fibula displaces the malleolus posterolaterally and widens the ankle mortise (Figs. 5-A and 5-B). There is frequently a coexisting tear of the tibiofibular ligaments, which aggravates the tendency to diastasis.

Since the lesion is produced by external rotation, it is only necessary to maintain the foot in slight internal rotation until healing is complete. Unfortunately, the customary short-leg plaster boot often fails to do this. As the initial swelling subsides and the calf muscles atrophy, the boot becomes quite loose and no longer protects the mortise against the spreading effect of day-to-day torsional stresses. It is not surprising, therefore, that

occasionally one finds "healed" cases which display appreciable widening of the mortise, with all its attendant disability[12], even though the roentgenograms taken immediately after reduction demonstrated good position in the cast. The worrisome feature of these injuries is more the diastasis than the fracture itself; consequently, in those cases which show any tendency to diastasis, it would seem advisable to extend the cast up to the groin, so as to immobilize the knee in semiflexion and hold the foot securely in internal rotation until the mortise is stable. When callus can be demonstrated and when diastasis can no longer be elicited, it is safe to change to a short leg boot.

The medial malleolus is also vulnerable to external-rotation stress, either as a solitary lesion or as part of a bimalleolar fracture. Ashhurst and Bromer are inclined to regard most solitary fractures of the medial malleolus as abduction injuries; but, while abduction doubtless plays a role through tension on the deltoid ligament, the present authors believe that the obliquity of the fracture line and the anterior displacement of the malleolar fragment (pointed out by Stevens) suggest primarily a torsion mechanism. In the light of our imperfect evidence on traumatic stresses, however, it would be presumptuous to draw a hard and fast line between abduction and external rotation. Strictly speaking, there is a distinction: External rotation signifies an outward deviation of the point of the foot around the longitudinal axis of the leg, whereas abduction signifies an outward deviation of the sole around an anteroposterior axis through the mortise. In practice, however, the distinction becomes artificial, since these movements take place simultaneously and shade into each other so gradually that one cannot say where abduction leaves off and external rotation begins. They are functionally very closely related; indeed, Whitman used the terms synonymously. Clinically, one can recognize many more "pure" external-rotation than abduction injuries, and so we have included abduction stresses under this heading.

FIG. 7

FIG. 8

Showing a pair of external-rotation injuries,—spiro-oblique fractures of the lower portion of the tibia and the upper portion of the fibula. Usually these occur in combination, although here they happened to be solitary fractures.

Ligamentous injuries due to external rotation are very common, not only as complications of malleolar fractures, but also as solitary lesions of major significance in their own right [1,6]. Two of the more important lesions are tears of the deltoid ligament and of the inferior tibiofibular ligaments. These structures are intimately related to the integrity of the ankle mortise; any widening of the tibiofibular syndesmosis or lateral displacement of the talus is necessarily accompanied by disruption of one or both of these ligaments. Unfortunately, the extent of the damage, particularly in tibiofibular diastasis, is usually not apparent in the routine roentgenograms, since by the time the patient arrives at the hospital, with his boots off and emergency splints already applied, the diastasis has been reduced spontaneously, and there is nothing to be seen but soft-tissue swelling. For an accurate appraisal of the ligamentous damage, it is necessary to manipulate the joint under anaesthesia and to supplement the standard roentgenograms with special views to demonstrate any latent instability of the mortise [23] (Figs. 6-A and 6-B).

FIG. 9

Fracture of the upper third of the fibula with diastasis of the ankle mortise, a combination described by Maisonneuve. This patient was not a parachutist; he fell from a ladder and landed sitting on the *outer* side of the left leg. The stress was evidently external rotation plus abduction. (Drawn from roentgenograms loaned by Arthur Krida, M.D., Director of the Orthopaedic Service, Bellevue Hospital, New York City.)

Pure external-rotation injuries of the foot are uncommon, except for one interesting lesion,—avulsion fracture of the posterior process of the talus (Fig. 4). This is caused by excessive tension of the talofibular ligament, a strong structure that moors the fibula against the side of the talus. Under external rotary stress, this ligament, which itself is very resistant to injury, occasionally avulses its bony insertion to form a fragment resembling an os trigonum.

Proceeding up the leg, we find that the typical pattern of injury is a spiral fracture of the shafts of both bones, the tibia breaking at the juncture of the middle and lower thirds, and the fibula usually breaking in its upper third, or even through the neck (Fig. 2). This is a familiar lesion, encountered in skiing, football, and many other sports; and the torsional etiology is thoroughly established [17]. Indeed, the spiral pattern of fracture is characteristic of the failure of a brittle rod under torsion stress. If further confirmation of the mechanism were needed, it might be observed, during open reduction of the fractured tibia, that internal rotation reduces the fragments, whereas external rotation duplicates the original displacement. These spiral fractures, then, are etiologically similar to the external-rotation fractures of the foot and ankle, except that the disruptive effect of the torsion is manifested at a higher level.

Not all fractures of the leg involve both bones; occasionally the tibia alone fractures in the same characteristic location and spiral pattern (Fig. 7). Displacement in these cases is less severe than when both bones are broken, and the prognosis is much more favorable, since the intact fibula functions as an internal splint.

Isolated fractures of the fibula may occur anywhere along the shaft, or even obliquely through the head (Fig. 8). They are often associated with a diastasis of the tibiofibular syndesmosis, as pointed out by Maisonneuve, who apparently never encountered such a combination clinically, but nevertheless predicted it as an external-rotation injury. The presence of a high fibular fracture, therefore, should prompt the surgeon to examine the ankle for the other half of the combination. Generally, the ligamentous lesion at the ankle is minor, but sometimes it is so gross a dislocation that it completely overshadows the

FIG. 10-A

FIG. 10-C

FIG. 10-B

FIG. 10-D

Injuries due to "landing thrust". The impact is transmitted through the long axis of the foot and produces a chain of compression fractures of the metatarsal and tarsal bones. The next vulnerable structure is the posterior tibial margin (see Fig. 11).

fibular fracture, which may show in the roentgenogram as an unexpected finding (Fig. 9).

External torsion is definitely a factor in the common meniscal and ligamentous injuries of the knee, and also in the rare dislocations of the head of the fibula [14], which, in the authors' opinion, represent simply a variant of the torsional fractures of the head and neck of the fibula. Most of the serious tears of the knee ligaments were due to abduction stress during the opening shock, and will be discussed later in connection with that mechanism. Fully half of the fractures of the femoral shaft also were caused by the opening shock; the remainder were attributed to excessively violent landings, although there was almost invariably a spiral pattern, indicating an element of rotation as well. Even the neck of the femur is not immune to external-rotation stress. One encounters very few of these fractures in young men, but it is pertinent to recall Astley Cooper's observation that they are due, not to a fall on the greater trochanter, as is so commonly taught, but to outward rotation of the lower extremity. They represent, therefore, the uppermost link in the chain of external-rotation fractures.

Landing-Thrust Injuries

This stress has been elevated to the status of a primary traumatic mechanism by virtue of its prevalence in parachute jumping. Some of the resultant patterns in the foot are illustrated in Figures 10-A, 10-B, 10-C, and 10-D: dorsal dislocation of the great toe, fracture of the flexor sesamoid, impaction of the metatarsals, or crushing of the mid-tarsal bones, especially the navicular, which is frequently shattered by the hammer-like head of the talus under the terrific impact of landing.

FIG. 11

FIG. 12-A

FIG. 12-B

Fig. 11: A solitary vertical fracture of the posterior tibial margin. Displacement is characteristically slight; any posterior dislocation of the foot is almost invariably accompanied by a fracture of the fibular malleolus. (Compare with Fig. 12-B).

Figs. 12-A and 12-B: A pair of bimalleolar fractures with fracture of the posterior margin of the tibia. In Fig. 12-B, the component of landing-thrust stress is more evident, and there is frank posterior dislocation of the foot.

If the metatarsal and tarsal bones survive the force of the landing thrust, the next vulnerable structure is the posterior tibial margin, which receives the upward and backward impact directly from the talus and frequently splits off vertically as a triangular fragment (Fig. 11). Usually only a small portion of the tibial articular surface is detached, and since the ligamentous arrangement of the ankle is especially designed to resist backward disolcation of the tallus [11], displacement of the fragment is generally slight.

Solitary fractures of the posterior tibial margin were described as far back as 1909 by Meissner, rediscovered in 1915 as "Cotton's fracture" [8], and again rechristened during the War as the "paratrooper fracture" [13, 21]. The authors feel that this term is hardly justifiable, since the fracture is not unique among parachutists, but is apt to occur under any circumstances when the body falls forward as well as downward [12, 15]. Although posterior marginal fractures occur more often in combination with external-rotation injuries, the fact remains that they do exist as isolated primary lesions, so there is little reason to classify them as a "variant" or "third degree" [5] of external-rotation fractures. They show none of the morphological characteristics of torsional injuries. The mechanism is evident; Stevens' designation of "impact splits" is accurately descriptive, although the term "landing thrust" may be preferred, since it suggests the specific direction of impact, and also links these injuries generically with the impaction fractures of the metatarsal and tarsal bones.

Injuries of External Rotation Plus Landing Thrust

At the ankle, this mechanism is characterized by posterior marginal fractures, combined with any of the lesions produced by external torsion. All sorts of combinations and variations are possible, but the most common clinical patterns are the fractures of the lateral malleolus plus the posterior margin and the bimalleolar fractures with fracture of the posterior margin of the tibia (Figs. 12-A and 12-B). In contrast to the undisplaced fractures of the posterior margin, these multiple fractures are often complicated by posterior dislocation of the foot, since there is so much disruption of the mortise that its inherent stability is destroyed. Neither the bones nor the ligaments can provide effective support. Even after reduction, the foot tends to sag backward under its own weight,

FIG. 13-A

FIG. 13-B

FIG. 13-C

FIG. 13-D

More lateral displacement is shown here than in Figs. 10-A, 10-B, 10-C, and 10-D, indicating an element of external rotation in addition to the landing thrust. Multiple metatarsal fractures are particularly common, as shown in Fig. 13-B.

aggravated by muscle pull from the calf. This leads to a chronic posterior subluxation of the foot, distortion of the tibial articular surface, and permanent arthritic disability. There is abundant literature concerning these injuries, especially the "trimalleolar"

TABLE IV

MECHANISM OF INJURY IN 300 ANKLE FRACTURES

	No. of Fractures	Totals
External rotation (including abduction)		157
Oblique fracture of lower end of fibula	128	
Oblique fracture of fibula plus fracture of anterior tibial tubercle	2	
Medial malleolus	13	
Medial malleolus plus oblique fracture of fibula	13	
Medial malleolus plus comminuted fibula (abduction)	1	
External rotation plus landing thrust		83
Oblique fracture of fibula plus fracture of posterior tibial margin	55	
Medial malleolus plus posterior tibial margin	2	
Bimalleolar fracture plus fracture of posterior tibial margin	25	
Shafts of tibia and fibula (spiral) plus posterior margin	1	
Landing thrust		47
Solitary fracture of posterior tibial margin	47	
Adduction		8
Transverse fracture of lateral malleolus (excluding chip fractures)	3	
Bimalleolar fractures	4	
Medial malleolus	1	
Vertical compression		2
Extensive comminution of lower ends of tibia and fibula	2	
Undetermined mechanism		3
Total		300

fractures[12]. Many surgeons advise open reduction of the mortise and internal fixation of at least the medial malleolus and the posterior margin of the tibia; but whatever method of treatment is selected, reduction must be exact. It is essential to support the talus well forward under the tibia, and to secure an accurate realignment of the weight-bearing axes.

Metatarsal fractures (Fig. 13-B) form a notable group of injuries. Due to the special landing technique of parachutists, these fractures are much more prevalent than in civilian life, and in half of the cases there is more than one fracture in the same foot. They show a characteristic dorsolateral shearing and impaction of the metatarsal heads. Occasionally, there are superimposed injuries, such as cuboid fractures or the unusual split foot (Fig. 13-C), which confirm the "sideswiping" stress of external rotation.

In addition to the typical torsion fractures of the leg, described earlier, there are less frequent transitional fractures, showing characteristics of posterior thrust as well as of torsion. In some cases, a triangular fragment is detached from the posterior aspect of the shafts; in others, spiro-oblique fractures of the tibia and fibula are combined with vertical fractures of the posterior tibial margin. These combined lesions of the leg and ankle illustrate the fallacy of attempting to classify fractures according to their location rather than their underlying mechanism. Trauma does not respect the arbitrary boundaries between the foot, ankle, and leg. We have already seen that the same stress can produce multiple lesions at widely different levels. Furthermore, a geographic classification inevitably becomes involved and cumbersome. Consider, for example, Maisonneuve's fracture,—a diastasis of the tibiofibular syndesmosis combined with a fracture of the upper shaft of the fibula. Is this primarily an "ankle" lesion or a "leg" lesion? Certainly the diastasis at the ankle is of more serious consequence than the fractured fibular shaft. In an etiological classification, however, these anatomical considerations are of secondary importance, since both lesions fit into one category,— namely, external rotation.

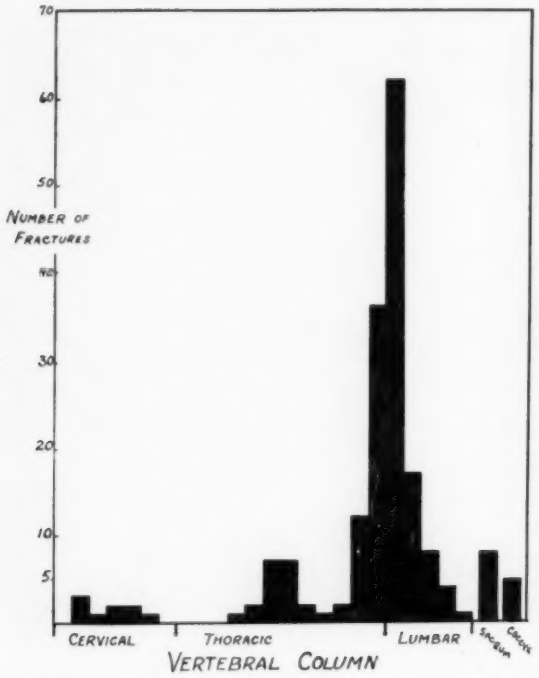

CHART 1

FIG. 14

Chart 1: Distribution frequency of vertebral compression fractures. Most of the fractures are concentrated at the thoracolumbar juncture. (Fractures of the second cervical vertebrae are all of the odontoid process.)

Fig. 14: Roentgenogram shows fracture of the mortise, due to adduction stress. The medial malleolar fragment is reminiscent of fractures of the posterior tibial margin. Both show a nearly vertical split, indicating direct thrust of the talus against the overhanging lip of bone.

Adduction and Internal Rotation

The most common result of adduction stress is the ordinary "sprained ankle",—that is, a tear of the fibulocalcaneal ligaments, often with a subperiosteal chip avulsed from the end of the fibula. Here, too, the important distinction must be made between partial tears and complete rupture of the ligament, since the presence of instability implies a totally different treatment and prognosis. Adduction fractures of the malleoli comprise less than 3 per cent. of our ankle fractures. They present a distinctive picture: a transverse fracture of the fibula at the level of the joint line, and a vertical split of the tibia through the medial angle of the mortise (Fig. 14). These fractures do not necessarily occur together; each has been observed as a solitary lesion.

Internal rotation probably contributes to most of the adduction fractures, but as a pure stress it has not yet been correlated convincingly with any specific injuries.

Summary

In order to recapitulate our experience with fractures of the ankle mortise, the authors have reviewed the last 300 fractures of the ankle; correlated the clinical, roentgenographic, and operative findings; and tabulated the injuries according to the traumatic mechanism (Table IV). As explained earlier, this arrangement depends upon the interpretation of circumstantial evidence, and one must beware of straining such evidence too far by postulating a theoretical sequence of trauma, or by intricate subclassifications, or tortured analogies with the laws of mechanics. The authors have tried to avoid these pitfalls of speculation. Table IV merely groups the fractures under well-recognized mechanisms, and it is with these mechanisms rather than with the minor variations in pattern that we are primarily concerned.

FIG. 15

Backward landings are dangerous. The parachutist's feet are swept out from under him, so that he lands directly on his buttocks; and the entire impact is transmitted to the spine.

A comparison of this cross section of the series with other reported groups of ankle fractures indicates that it makes little difference whether the ankle is broken by falling downstairs, stepping off a curb, playing football, or parachute jumping: From the point of view of *etiological stresses*, the statistical distribution of fractures is much the same. There are certain minor variations, such as the high incidence of posterior marginal fractures of the tibia, and the relatively low incidence of vertical compression fractures in this series. These differences, however, are trivial; the fundamental point of similarity is the preponderance of external-rotation injuries. External rotation and abduction, taken together, account for 75 per cent. of the fractures reported by Ashhurst and Bromer, Stevens, Moritz, and Bishop, as well as the present authors. This cannot be mere coincidence; the figures are consistently too high, and they are independent of the source of the patients or the circumstances of injury. One may reasonably conclude, therefore, that the vulnerability of the ankle to external rotation represents an inherent weakness of the joint,—either a local structural weakness, or else a lack of adaptive resiliency of the leg as a whole. This latter possibility gains support from the fact that not only the ankle, but the entire lower extremity, shows a statistical preponderance of external-rotation injuries.

BACKWARD LANDING

The second prime cause of injury among parachutists, especially among novice jumpers, is the backward landing. Again the hazard is oscillation: The jumper strikes the ground at the peak of a pendulum-like backswing; his feet are swept out from under him; there is no opportunity to roll or to cushion his landing; and he falls abruptly backward onto his buttocks and head (Fig. 15).

Vertebral fractures and craniocerebral injuries characterize this mechanism of injury. Practically all the vertebral fractures are of the compression type, the cancellous bone being crushed anteriorly by violent hyperflexion of the spine. Almost invariably, the superior surface of the vertebral body is compressed downward toward the inferior surface.

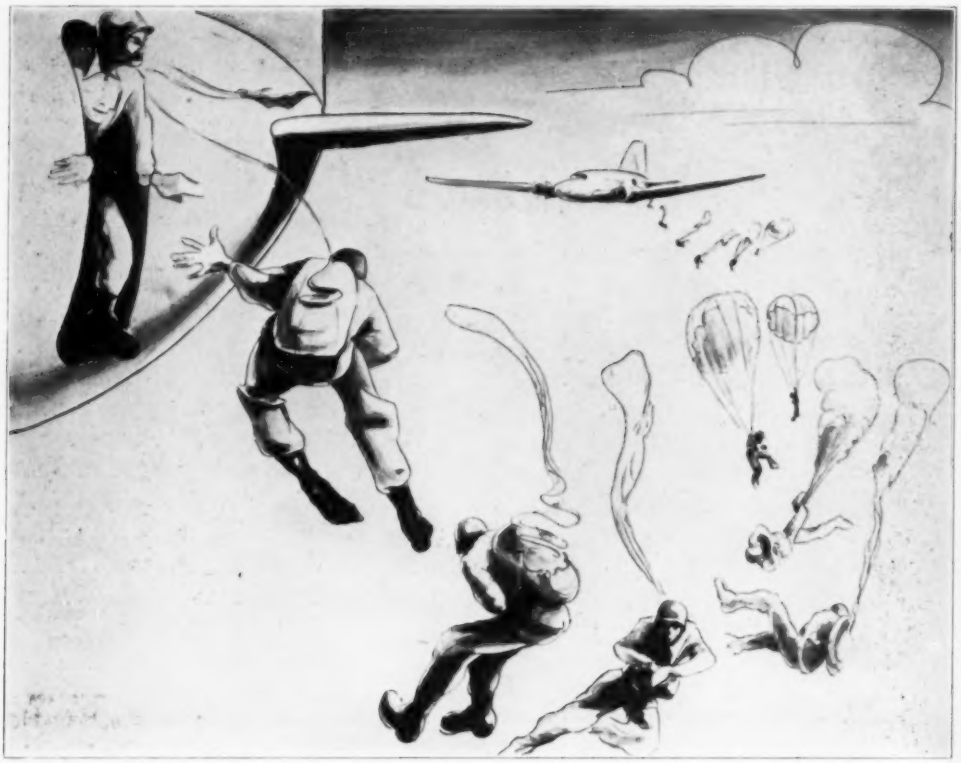

FIG. 16

As they rush out the door, parachutists occasionally trip and fall with poor body position. This composite drawing, made from slow motion pictures, illustrates several faulty positions which can cause opening-shock injuries. The third man from the plane, for example, has spun around too far and will receive a violent jerk when his parachute opens. The fifth man has caught his left leg in the suspension lines and will probably rupture the ligaments of the knee.

Fractures are not distributed uniformly throughout the spinal column. As indicated in Chart 1, the thoracolumbar segment is most commonly involved, particularly the first lumbar vertebra, and there is a secondary frequency peak in the mid-dorsal region.

One third of the cases show multiple fractures, not always in adjacent vertebrae. Paraplegia and dislocations were, fortunately, quite rare in our series. The absence of cord damage made it possible to treat all the thoracolumbar fractures by means of free hyperextension between two tables, according to the Watson-Jones technique. We consider this to be the method of choice for securing full reduction (that is, re-expansion) of the collapsed vertebral bodies.

Almost as potent a source of disability as the fractures themselves were the soft-tissue injuries of the spine,—the low-back sprains, herniated intervertebral discs, contusions of the coccyx, traumatic myositis, et cetera. It is difficult to assess the frequency of these injuries. Most parachutists are inclined to make light of minor injuries, and do not seek medical treatment unless they are practically disabled. Consequently, hospital statistics do not give a true picture of the situation. As an estimate, however, there were probably ten soft-tissue injuries of the spine for every compression fracture. Most of them may appear trivial at first, but the sequelae are notoriously troublesome, and in many men chronic low-back pain developed which ultimately disqualified them from further parachute duty.

Sometimes these backward landings are so violent that, even with the protection of a special helmet, the parachutist is knocked unconscious when his head slams against the ground. A survey of the hospital records revealed 110 cases of head injury, ranging in severity from a momentarily dazing concussion to cerebral laceration and fatal intra-

FIG. 17-A

FIG. 17-B

FIG. 17-C

Fig. 17-A: Diastasis of the symphysis pubis. Fig. 17-B: Spiral fracture of the femur.
Fig. 17-C: Rupture of the medial collateral ligaments of the knee.
All of these opening-shock injuries are caused in the same way: The parachutist's left leg becomes entangled in the suspension lines and, when the parachute opens and suddenly checks his fall, the shock is transmitted to the leg as a violent abduction stress.

cranial hemorrhage. Doubtless many others occurred; but, as with other soft-tissue injuries, the milder cases were not reported, and the men recovered without benefit of hospital treatment. Head injuries will not be discussed here, since they are primarily neurosurgical problems, particularly in view of the incidence of residual headaches and other distressing sequelae.

OPENING SHOCK

As a mechanism of injury, the opening shock is unique in that there is no contact with the ground or with any other unyielding object; the damage is done in mid-air by the sudden snubbing action of the parachute against the momentum of the falling body. The likelihood of injury depends upon the position of the parachutist's body at the moment the parachute opens: If he has jumped from the plane correctly, the shock is well distributed by the harness and is absorbed with little discomfort; but if he dives, somersaults, or spins into a vulnerable body position, the violent jerk of the parachute can be very dangerous.

There are two general types of injury:

1. *Whip-lash:* Here the jumper is out of line with the tug of the opening parachute, which flips him upside down with a sort of whip-lash effect. Relatively minor injuries are the rule, such as sprains of the neck, transient neuropathies of the brachial plexus[19], and ecchymotic brush burns over the clavicles from the slap of the "risers".

2. *Suspension-Line Injuries:* Occasionally an arm or leg becomes entangled in the suspension lines while the parachute is unfurling from its pack (Fig. 16). Before the jumper can disentangle himself, the slack lines suddenly pull taut and wrench the extremity with great violence, rupturing ligaments, muscles, and even the bones themselves (Figs. 17-A, 17-B, and 17-C). The magnitude of the stress is attested by the fact that over half the fractures of the humerus and 40 per cent. of the fractures of the femur were caused in mid-air by this bizarre mechanism. Even more common were tears of the medial collateral and cruciate ligaments of the knee; over sixty-five of these cases with frank instability have already been reported in some detail[18]. Other very serious injuries were encountered, such as dislocation of the shoulder (ten cases), diastasis of the symphysis pubis (three cases, as well as an additional case reported by Anderson), laceration of the perineum and rectum[14], tears of the biceps and coracobrachialis muscles, and even amputation of a finger. This last accident occurred when the suspension lines caught underneath a ring and avulsed the entire digit. Opening-shock injuries will not be discussed further here, since they are primarily the concern of the military surgeon; from an etiological point of view, they have no counterpart in civilian life at the present time.

VIOLENT VERTICAL LANDINGS

The American combat parachute assembly is designed to provide a normal rate of fall of twenty feet per second. This is subject to some variation, depending upon the gross weight of the parachutist and his equipment; but, if there is not too much ground wind or oscillation, the landing impact is reasonably safe,—equivalent to that of a seven-foot drop.

Unfortunately, however, the rate of fall is not always so gentle. There are occasional mishaps, rather euphemistically termed "malfunctions", in which the parachute fails to inflate properly and the rate of vertical fall is accelerated dangerously. This can happen in a number of ways: The suspension lines may become tangled or fouled across the parachute, a panel of the silken canopy may be ripped by the force of the opening shock, or the jumpers may drift too close together and, like sailboats, spill the air from each other's parachute.

Regardless of the technical details of the accident, the ultimate effect is the same: The normal parachute support is reduced, the landing impact is exaggerated far beyond the structural resistance of the body, and extremely severe and often spectacular injuries result. A few cases will serve to illustrate the general nature of the group:

FIG. 18-A

FIG. 18-B

Both of these injuries are due to indirect violence. The high fibular fracture, the low tibial fracture, and the spiro-oblique patterns of Fig. 18-A characterize it as a torsion injury. In Fig. 18-B, the transverse fracture lines, the comminution, and the fact that both tibia and fibula broke at the same level indicate that the injury was due to axial-compression stress. This is the pattern seen in the violent vertical landings.

CASE 1. This patient became entangled with another parachutist in mid-air. The following injuries resulted: (a) compression fracture of the first lumbar vertebra; (b) fracture-dislocation of the body of the fourth lumbar vertebra; (c) comminuted fractures of the shafts of the left tibia and fibula; (d) multiple fractures of the pelvis, involving the right acetabulum and left pubic rami; (e) multiple fractures of the right tarsal bones, including the talus, superior border of the calcaneus, the navicular, and the head of the fifth metatarsal; and (f) cerebral concussion.

CASE 2. A delayed parachute opening was responsible for (a) compression fractures of the first and second lumbar vertebrae; (b) transverse fractures of the shafts of the left tibia and fibula (Fig. 18-B); and (c) comminuted fracture of the mid-shaft of the right fibula.

CASE 3. A violent landing, of undetermined cause, produced (a) compound fracture of the shaft of the right femur, and (b) simple fracture of the shaft of the left femur.

CASE 4. This man became entangled with another parachutist in mid-air, and suffered the following injuries: (a) comminuted intertrochanteric fracture of the left femur, and (b) comminuted fractures of the shafts of the left tibia and fibula.

These injuries have little in common, except that they are multiple and involve the major weight-bearing structures, especially the long bones and vertebral column. Many of

the vertebral fractures are apparently produced by violent "jackknifing" into a squatting position, instead of a simple fall onto the buttocks. Some of the fracture patterns due to vertical compression are fairly distinctive. The tibia and fibula, for example, do not show the smooth spiral patterns characteristic of torsion fractures; instead, the bones break transversely at the same level, usually with extensive comminution (Figs. 18-A and 18-B). Occasionally, the lower end of the tibia is shattered completely in a T or Y fashion, but this does not occur so frequently as one might expect; a more common lesion in this location is a simple impact split of the *anterior* tibial border [15]. Another favorite lesion is a transverse shearing fracture through the neck of the talus.

Remarkably few fractured heels were encountered. Most of those listed in Table I were minor cracks or chips, rather than the severe compressions that one would expect from such violent landings. No doubt this is due to the fact that parachutists are trained to land with the legs semiflexed and springy, as shown in Figure 1, which permits the impact to be absorbed in the muscles and so spares the calcaneus from the crushing effect of a stiff-legged fall.

It would be interesting from a biophysical point of view to calculate the velocity and inertia of these accelerated landings, in order to formulate some values for the stress tolerance of the human body [9]. Unfortunately, however, there are so many indeterminate factors in parachute jumping—the nature of the terrain, the vagaries of wind, oscillation, and malfunctions, as well as the skill of the jumper—that an analysis of quantitative stress is out of the question. One must be content with a qualitative recognition of the mechanisms of injury. For all clinical purposes this is enough, for it is the nature of the trauma more than the degree which determines what kind of injuries will be produced. The mechanism of injury is fundamental in the study of trauma, and it is on this basis that fractures should be classified. Such a classification transcends the accidents of circumstance, simplifies the innumerable variations of pattern, and provides the key to intelligent treatment.

SUMMARY

1. This survey describes a series of 3,000 fractures and major soft-tissue injuries resulting from parachute jumping, with particular reference to the traumatic mechanisms involved.

2. Almost all injuries involve weight-bearing structures. The distribution and patterns of injury are generally similar to those encountered in civilian orthopaedic practice; yet there are certain minor statistical differences which are related to the peculiar stresses of parachute jumping. No injury is specific enough to be called a typical parachute lesion.

3. Almost all the injuries of parachute jumping can be attributed to four basic traumatic mechanisms:

(a) Torsion plus landing thrust. This is by far the most common mechanism of injury and is responsible for a chain of related injuries, extending from the toes to the hip.

(b) Backward landing. Vertebral compression fractures and head injuries characterize this mechanism of injury.

(c) "Opening shock" is a mechanism of injury peculiar to parachute jumping. The violent abduction stress causes many ligamentous tears and even fractures of the extremities.

(d) Violent vertical landings. Occasional parachute malfunctions increase the landing impact and cause severe multiple fractures of the legs and spine.

4. One-half of all parachute fractures involve the ankle mortise. Various authors report essentially the same statistical distribution of fractures as in the present study, although the source of the patients and the circumstances of injury are all different. The most prevalent mechanism of injury is external rotation which, together with abduction, accounts for approximately 75 per cent. of fractures at the ankle.

5. The entire lower extremity shows a preponderance of external-rotation injuries. This would imply a structural weakness of the limb as a whole,—a lack of adaptive resiliency to the stress of external torsion.

6. A classification of fractures based on etiological stresses is much more reasonable and useful than one based on anatomical location. Recognition of the etiological stresses not only relates apparently dissimilar fracture patterns, but also provides a rational approach to treatment.

NOTE: The authors wish to express their appreciation to Bernard Ryan, M.D., and to Captain Darwin Kitch, U. S. Army, for technical advice in the preparation of this paper; and also to Mr. Erich Layer, who, while a prisoner of war, made the drawings for Figures 2, 15, and 16.

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STYLOIDECTOMY OF THE RADIUS IN THE SURGICAL TREATMENT OF NON-UNION OF THE CARPAL NAVICULAR

A Preliminary Report *

BY LEONARD BARNARD, M.D., OAKLAND, CALIFORNIA, AND SAM G. STUBBINS, M.D., CLEVELAND, OHIO

During the past two decades the diagnosis and treatment of recent fractures of the carpal navicular have been freely discussed and, in large degree, standardization of management has resulted. Unfortunately, this is not true of the large group of patients who present non-union when first seen. For the treatment of this latter condition, there are advocates of excision of the bone, bone-grafting, and wrist fusion [4, 7]. Böhler states that he has never seen a normally functioning wrist after complete excision of the navicular; the authors agree with him in condemning this approach to the problem, although admitting that small fragments should be excised. Wrist fusion has its place, but it should be reserved for the very severe cases of late arthritis. The more recent reports [5, 8] show the trend definitely and logically toward bone-grafting as the best solution. The type of bone-grafting preferred is an autogenous implant through a drill hole or holes. The older method of treatment by drilling resulted in too many failures and has been largely abandoned.

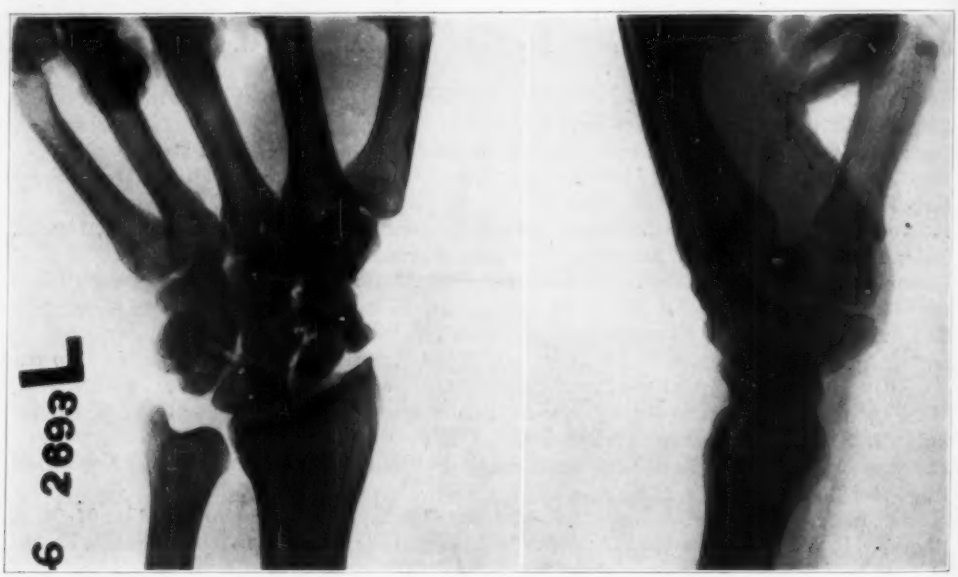

Fig. 1

Note the marked degenerative changes about the styloid process of the radius in this case of old ununited fracture of the navicular.

The role of the styloid process of the radius in fractures of the carpal navicular has been given attention by a few authors. Schnek pointed out that a large styloid process predisposes to this fracture. Others feel that the process acts as a fulcrum, over which the waist of the navicular is compressed when it receives the force producing fracture. Pronounced degenerative arthritic changes about the radial styloid are commonly observed in old cases of non-union of this bone (Fig. 1). This we believe to be the result of increased strain thrown upon the radial collateral ligament of the wrist at its styloid attachment, plus the trauma of abnormal movement of the distal fragment against the process when it

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1947.

FIG. 2-A

FIG. 2-B

Fig. 2-A: F. D. This patient had a malunited navicular, which impinged against the radial styloid on flexion of the radius, limiting motion and causing pain. Preoperative film shows the malunion, with definite impingement of the navicular against the styloid.

Fig. 2-B: After removal of the styloid, both the motion and the symptoms were definitely improved.

Fig. 3: Schematic drawing of procedure. The styloid process is excised and used for indwelling graft.

moves with the distal row rather than with the proximal row of carpal bones.

In radial flexion of the wrist joint, the navicular slides ulnarward along the slanted concave surface of the distal end of the radius. In so moving, it tilts anteriorly on its long axis, so that the tuberosity of the navicular moves anterior to the radial styloid. Slight motion of the wrist in the presence of fractures of the navicular waist causes the two fragments to move independently of each other. The distal fragment butts against the styloid of the radius, moving more with the distal row of carpal bones; while the proximal fragment, being adherent through the capsule to the lunate, moves in a different plane with the proximal row of carpals. This mechanism produces a shearing stress at the fracture line, and is as large a factor in non-union as the known avascularity of this bone.

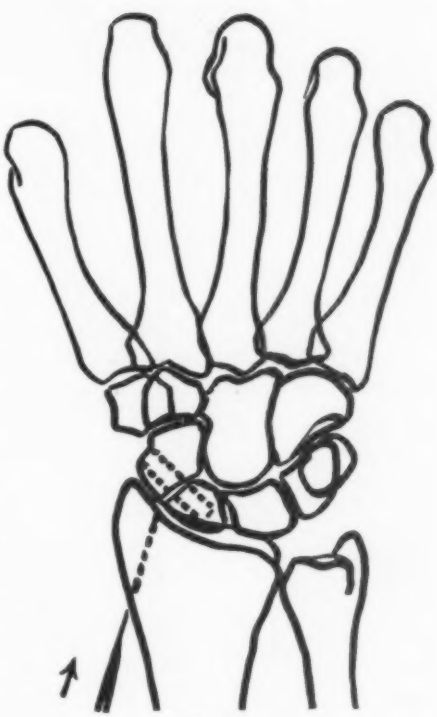

FIG. 3

The observation that a normally functioning wrist joint followed wounds which caused avulsion of the radial styloid, as well as the finding of marked displacement of the

process without discomfort in fractures, led to the consideration of sacrificing it surgically. The authors' first case (Figs. 2-A and 2-B) was one of a malunited navicular with definite

FIG. 4-A

FIG. 4-B

Fig. 4-A: J. H. Patient sustained fracture of navicular in a fall in August 1942. Bone-pegging and radial styloidectomy were carried out in September 1945. The patient was immobilized in a circular plaster for eight months before solid bony union took place. Film shows wrist before operation.

Fig. 4-B: Postoperative roentgenogram, showing result of minimum styloidectomy. Cortical bone from the tibia was used to form the bone peg employed in fixation.

FIG. 5-A

FIG. 5-B

Fig. 5-A: E. S. Preoperative roentgenogram of patient who fractured his carpal navicular in a boxing match in 1941.

Fig. 5-B: Radial styloidectomy and bone-pegging were done in June 1946. Patient was immobilized in skin plaster for three months after operation. Roentgenogram shows evidence of solid bony union. Cancellous bone from the radial styloid was used for the graft.

impingement against the process; removal of the radial styloid alleviated the symptoms. Hope of being able to release some of the shearing stress at the fracture site and of preventing secondary arthritic changes led to the development of the operative procedure described here (Fig. 3).

OPERATIVE TECHNIQUE

With the wrist held by an assistant in mid-pronation and ulnar deviation, the operative approach is made, after the technique of Burnett, through the anatomical snuffbox, with a three-centimeter incision directly over the radial styloid, between the extensor pollicis longus and the abductor pollicis brevis. Before operation, care should be taken to locate the radial artery as it courses dorsally; this is assured by palpation of its pulse, as its position was found to vary markedly. If the radial artery turned obliquely across the snuffbox it could be more readily retracted posteriorly, along with the superficial branch of the radial nerve and the extensor pollicis longus. More commonly it can be retracted anteriorly, with the abductor pollicis brevis and extensor pollicis brevis. The periosteum over the styloid process is then incised in the long axis, together with the capsule of the wrist joint, which at this point is largely the radial collateral ligament. The process is then freed subperiosteally of all soft tissue and removed with an osteotome.

The method of removal depends upon whether or not the styloid process is to be used for the carpal graft. If the bone is to be used in grafting, the incision should start 1.5 centimeters up the radial shaft, in order to secure a sufficiently large fragment to be reshaped for this purpose. Upon removal of the process, the navicular will be found to lie directly in the wound; and in most instances the fracture will be visible. The tuberosity can then be exposed easily, with avoidance of its dorsal arterial supply; a drill can be carried across the fracture line under visual control; and the graft can be inserted in the routine manner. The authors preferred using the removed fragment of styloid for the graft, because it could be obtained in the same field; since it was largely cancellous bone with a thin cortex, it was ideally suited for this purpose. Interestingly, the articular cartilage over the distal end of the radius does not extend up onto the styloid process. The wound is closed in layers, the radial collateral ligament being sutured over the raw bony surface of the radius. A plaster-of-Paris cylinder is applied, with the wrist in moderate dorsiflexion and the thumb included in functional position.

RESULTS

To date the authors have performed fourteen such operations, extending over a period of two and one-half years. The end results of ten are available. Union was obtained in nine, both clinically and by roentgenogram, and the functional results were good. The time interval after operation varied from three to seven months. The procedure failed in one case because the proximal fragment was too small. In this case, grafting was not justified; the small proximal fragment should have been excised. Two of these cases were done with tibial grafts, and in seven instances the styloid was used. In addition, simple styloidectomy for a malunited navicular has been performed in three cases, with excellent results. No appreciable instability of the wrist joint has been noted in any of the cases in which the radial styloid was removed.

CONCLUSIONS

The surgical removal of the radial styloid process is presented as an aid in the treatment of malunited and ununited fractures of the carpal navicular. It is believed to simplify the surgical approach, and ensures better visualization and immobilization of the fracture fragments, as well as less likelihood of secondary degenerative arthritic changes. By employing the excised styloid fragment for grafting material, the whole operative procedure can be confined to a single operative field.

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DISCUSSION

Dr. Ralph Soto-Hall, San Francisco, California: The large number and the wide variety of operations which have been suggested for the treatment of this condition reflect well the difficulty in solving this problem. I believe that the authors have contributed a valuable idea to the surgical treatment of non-union of the carpal scaphoid. However, as in all new procedures, the problem is to determine accurately the type of case for which the operation is suitable.

Non-union of the scaphoid is complex, because of the variety of pathological changes which may be associated with it; and the degree and the severity of these changes must determine our choice of treatment.

I agree with the authors that drilling should be discarded, and also that ununited fractures of the proximal pole give excellent function when treated by removal of the small fragment. On the other hand, total excision of the scaphoid gives a poor result early and a worse one later. I have followed several patients with total excision for a number of years and have noted a considerable shifting in the relationship of the carpal bones,—which explains the progressive increase in symptoms. In early cases without anatomical change, a simple bone graft answers our problem in over 90 per cent. of the cases.

In non-union of long standing we often find a mechanical arthritis of severe degree, with disappearance of the articular cartilage between the scaphoid and the radius, hypertrophy of the radial styloid; and an important, but often overlooked, subluxation or tilting of the lunate.

When these changes are severe, simple grafting or styloidectomy will not correct the disability. In these patients, particularly those engaged in manual labor, a radiocarpal arthrodesis will give a sound, painless wrist. This procedure I still believe to be the most effective one when the fundamental mechanics of the wrist have been deranged.

Total excision of the proximal carpal row is another procedure which is applicable in the late cases; but it has limited use, because too often there is residual pain and weakness.

It seems, therefore, that a fairly large number of moderately old cases of non-union exist with not too advanced deformity, which should be ideally suited for a more conservative procedure, such as that described. I have not performed this operation on the living but, after reading the authors' paper, I experimented on the cadaver. I was able to confirm the authors' clinical findings that styloidectomy does not produce instability of the wrist and that it does reduce the strain and movement at the site of the experimentally produced fracture. The approach is simple and the exposure obtained is excellent.

I want to congratulate the authors for presenting a procedure which, although not a cure-all, will, I believe, in well-chosen cases, become a permanent help in this type of surgery.

Dr. Leonard Barnard (closing): I wish to thank Dr. Soto-Hall for his kind remarks. I have one comment to make. While Dr. Soto-Hall recognizes that in early cases, without arthritic changes, simple bone-grafting gives a large proportion of good results, we see few of these cases early.

DISTURBANCE OF LONGITUDINAL GROWTH ASSOCIATED WITH PROLONGED DISABILITY OF THE LOWER EXTREMITY *†

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Impaired function of an extremity during its longitudinal growth may result in a discrepancy of limb length. Paralysis, skeletal infection, trauma, and congenital anomalies are among the common causes of impaired function. In such cases, the inequality of limb length is the result of growth retardation and does not entail premature closure of epiphyseal cartilage.

In some patients, however, marked length discrepancy or alignment deformity develops; and in these cases, premature closure of one or more epiphyseal discs can usually be demonstrated. These growth arrests occur in patients who have had prolonged disability of an extremity. They are not due to destruction of epiphyseal cartilage by involvement with the primary disease, but are the late consequences of deranged limb function.

This paper is concerned with premature closure of the growth cartilages at the knee in those patients who have had prolonged dysfunction of the lower limb. It is based on the study of thirteen patients, nine of whom had tuberculosis of the hip. Each of the others had pyogenic arthritis of the hip, slipped capital femoral epiphysis, poliomyelitis, or osteomyelitis of the shaft of the femur. Six patients were boys; seven were girls.

The frequency of this complication is difficult to estimate, because its recognition requires observation of the patient during several years of growth. Nine cases with growth arrest at the knee were found in a group of ninety-two patients with tuberculosis of the hip. This incidence of 10 per cent. suggests that, after tuberculosis of the hip, growth arrest at the knee is more frequent than the literature indicates. Gill's report of fifteen patients in whom this complication developed stands alone in the literature.

In the cases here recorded, the site of the growth arrest at the knee varies. In five patients, growth arrest occurred in both the distal femoral and proximal tibial epiphyseal plates. Premature closure of the distal femoral disc occurred centrally in all five; but, in the tibial disc, it occurred peripherally in four, centrally twice. (One patient had bilateral tuberculosis of the hip, and growth arrest at both knees developed.) In eight patients growth arrest of the proximal tibial epiphyseal cartilage alone developed. In this group, peripheral fusion of the plate occurred six times and central fusion twice. Seven of the peripheral arrests occurred in the posterior medial quadrant and three in the anterior quadrant of the tibial plate. The proximal fibular disc was not affected in any case.

CASE REPORTS

CASE 1. T. M., a boy, aged five, had had advanced, untreated tuberculosis of the right hip for three years. Immobilization of the hip for four months preceded arthrodesis with a tibial transplant. This was followed by immobilization for two years and ten months. Two years later, flexion-adduction deformity of the right femur was corrected by subtrochanteric osteotomy. Plaster fixation for two months was necessary after this operation. The total period of immobilization of the left lower extremity was three years and four months.

Growth arrest occurred in both major epiphyseal cartilaginous discs at the right knee. It developed first in the distal end of the femur, where there was evidence of growth disturbance two and one-half years before bony fusion of the epiphysis and the metaphysis was apparent. A roentgenogram (Fig. 1-A) of the right knee, taken upon entry, showed osteoporosis, but no abnormality of the growth cartilages. After two

* Presented at the Chicago Orthopaedic Society on March 14, 1947.
† This work was supported in part by the Douglas Smith Foundation.

FIG. 1-A FIG. 1-B FIG. 1-C

Case 1, T. M. Roentgenograms of knee.
Fig. 1-A: At the age of five, showing osteoporosis, but no abnormality of the epiphyseal discs.
Fig. 1-B: At the age of seven and one-half, showing thinned distal femoral plate and a radiolucent defect (*a*) in distal femoral metaphysis.
Fig. 1-C: At the age of ten, showing fusion of the central portion of the distal femoral disc and of the medial portion of the proximal tibial plate. There is posterior rotation of the femoral condyles and proximal overgrowth of the head of the fibula.

and one-half years of immobilization, a roentgenogram (Fig. 1-B) showed more marked osteoporosis, a thinned and irregular distal femoral disc, and a circumscribed area of rarefaction in the adjacent metaphysis. The growth cartilages of the tibia and fibula appeared normal. At the age of ten, one year after removal of plaster fixation, roentgenograms (Fig. 1-C) showed central closure of approximately two thirds of the distal femoral disc. Less extensive closure was present in the medial portion of the proximal tibial plate. Proximal overgrowth of the fibula was present. In both the femur and the tibia, the location of the growth arrest was eccentric and had resulted in posterior rotation of the condyles of the femur and flexion of the shaft of the tibia. The area of rarefaction in the metaphysis was no longer evident. Inequality of limb length at this time was ten centimeters; seven and five-tenths centimeters of this shortening was in the femur and two and five-tenths centimeters in the tibia.

Case 2. J. S., a boy, aged two and one-half, had tuberculosis of the right hip. Growth arrest in the central portion of the proximal tibial cartilaginous plate developed. Although the distal femoral plate ceased its longitudinal growth, it did not undergo premature ossification. Following immobilization of the extremity in plaster for sixteen months, an arthrodesis of the hip was performed. Further immobilization was carried out for fifteen months. Bony ankylosis of the hip was present at the age of five. Five years later, there was seven and five-tenths centimeters of shortening of the right lower extremity. Prominence of the head of the right fibula was noted. A roentgenogram (Fig. 2-A) demonstrated bony bridging of the proximal tibial plate at its center. There was also proximal displacement of the head of the fibula. The distal femoral disc appeared normal, but there was an irregular radiolucent defect in the distal femoral metaphysis adjacent to the center of the growth cartilage. Osteotomy of the proximal end of the tibia, with excision of most of the epiphyseal cartilage, was done in order to correct the deformity of the right knee. The prominent head of the right fibula was also removed. A roentgenogram (Fig. 2-B), taken two years later, showed that the proximal tibial epiphyseal plate had closed. The distal femoral epiphyseal plate was still open, but its relationship to the metaphyseal defect had not changed, indicating that longitudinal growth from it had ceased.

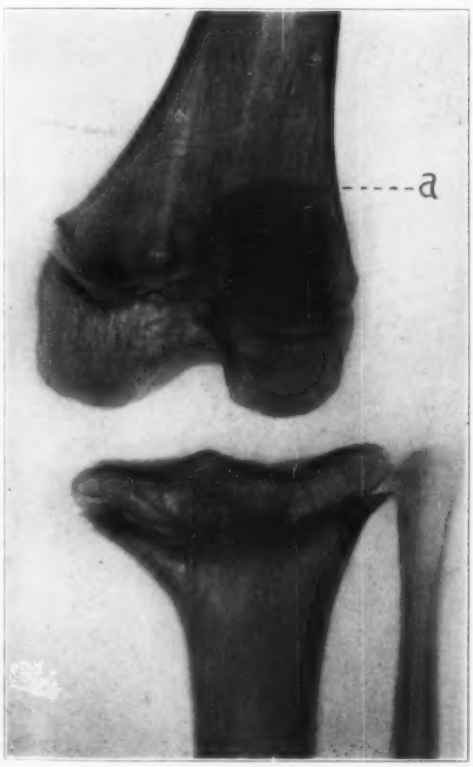

Fig. 2-A

Fig. 2-B

Case 2, J. S. Roentgenograms of knee.

Fig. 2-A: At the age of ten, showing bony fusion centrally of proximal tibial plate, proximal displacement of head of fibula, and a radiolucent defect (*a*) in the distal femoral metaphysis. (Roentgenogram has been reversed.)

Fig. 2-B: At the age of twelve, showing that the radiolucent defect has not been displaced or elongated. More extensive bony fusion of the proximal tibial disc is present. (Roentgenogram has been reversed.)

The inequality between the lengths of the femora was two centimeters and between the tibiae was five centimeters.

Microscopic sections of the tibial and fibular epiphyseal discs, removed at the time of osteotomy, are shown in Figures 2-C, 2-D, and 2-E. Fibrillation and fissuring of the matrix was present and the cartilage-

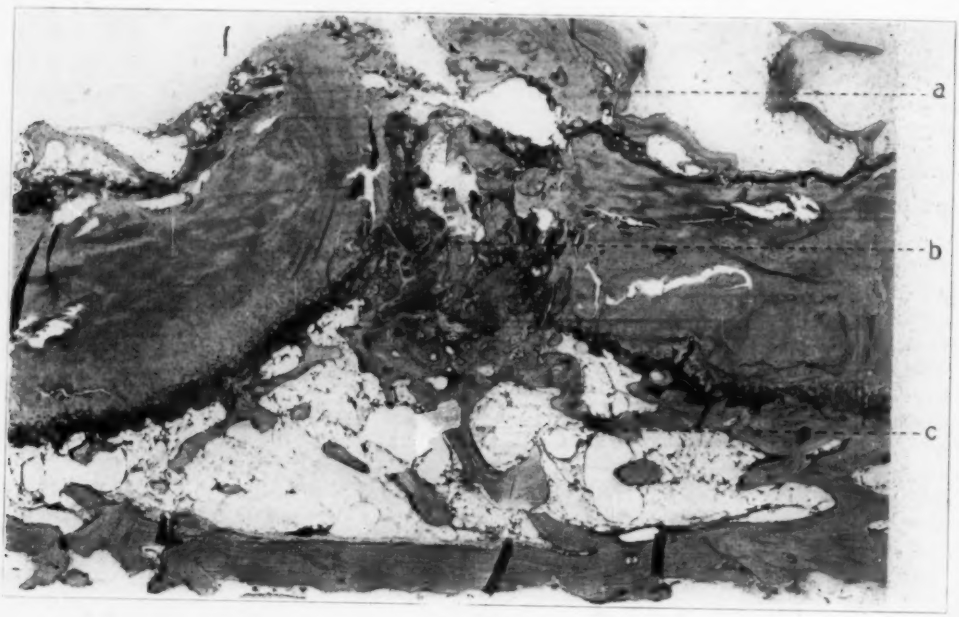

FIG. 2-C

Photomicrograph (×15) of central portion of proximal tibial plate, showing fibrous tissue and bone (*b*) uniting epiphysis (*a*) to metaphysis (*c*).

FIG. 2-D

Photomicrograph (×100). Peripheral portion of proximal tibial plate, showing fibrillation and fissuring of cartilage matrix. The cartilage-cell columns (*a*) are disorientated and shorter than normal.

cell columns of the tibial cartilaginous disc were disorientated. The fibular epiphyseal cartilage appeared normal.

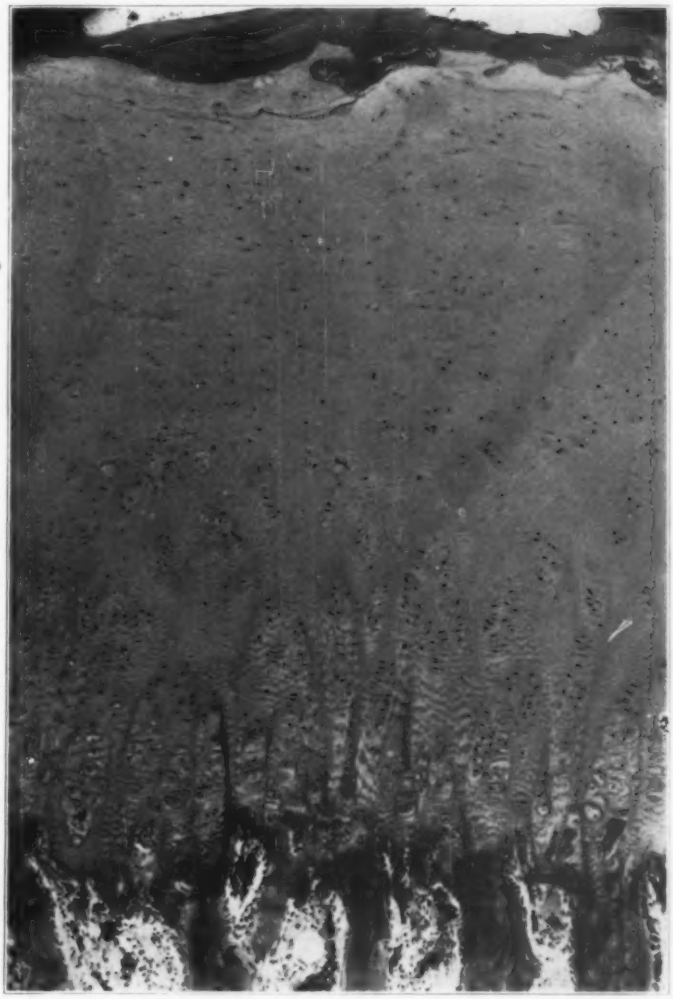

FIG. 2-E

Photomicrograph (×100). Proximal fibular epiphyseal plate is normal.

When the area of arrest of a plate is eccentric, the unaffected portion continues to grow and will cause recurrence of alignment deformity unless corrective osteotomy is accompanied by surgical completion of the growth arrest. The following patient had two recurrences of tibia vara because this was not recognized.

CASE 3. H. B., a girl, aged ten, had had tuberculosis of the left hip since the age of two and one-half. Intermittent immobilization of the left lower extremity had been carried out for three years during the period of three and one-half to seven and one-half years of age. At entry, a varus deformity of the left knee was present. There was ten centimeters of inequality in limb length, due, in part, to a pathological dislocation of the left hip. A roentgenogram of the knee upon admission demonstrated complete bony fusion of the distal femoral cartilaginous disc and partial bony union of the medial portion of the proximal tibial plate to the metaphysis. The lateral portion of the epiphyseal plate was open, and its continued growth was indicated by the fact that there was no proximal overgrowth of the head of the fibula. The tibia vara was corrected by wedge osteotomy through the proximal tibial metaphysis. Failure to complete the growth arrest of the tibial plate resulted in recurrence of the tibia vara two years later. A second osteotomy was performed through the proximal tibial metaphysis. Again, failure to complete the growth arrest resulted in recurrence of the deformity. At the age of twenty, tibia vara of the left knee and inequality of limb length of seventeen centimeters were present.

Case 4 demonstrates the relationship of growth retardation and growth arrest to prolonged disability of the lower extremity.

CASE 4. D. P., a girl, aged twelve, had pyogenic osteomyelitis of the distal two thirds of the shaft of the right femur.

A roentgenogram (Fig. 3-A), at the age of two, showed osteomyelitis and a pathological fracture of the shaft of the femur. Osteoporosis of the femur and tibia was present, but the growth discs appeared normal. At the age of four, a roentgenogram (Fig. 3-B) showed the following changes of both the distal femoral and proximal tibial discs, which indicated growth retardation: The femoral plate rose to a peak in the center of the metaphysis, the tibial disc showed a less well-developed central peak, and the head of the fibula was displaced proximally by its more rapid growth. Osteoporosis was not pronounced, because the patient had been ambulatory. Growth-arrest lines were present in the distal femoral and proximal tibial epiphyses. Six years later, at the age of ten, a roentgenogram of the knee revealed that both the femoral and tibial epiphyseal plates were still open. At the age of eleven, a roentgenogram (Fig. 3-C) showed the beginning of a bony bridging of the proximal tibial disc. The distal femoral plate was still open, and its contour was more evenly

FIG. 3-A FIG. 3-B FIG. 3-C

Case 4, D. P. Roentgenograms of the knee.

Fig. 3-A: At the age of two, showing osteomyelitis of shaft of femur, but normal epiphyseal cartilages.

Fig. 3-B: At the age of four, showing healed osteomyelitis of the shaft of the femur. A central peak in the distal femoral plate and proximal displacement of the head of the fibula indicate growth retardation of the distal femoral and proximal tibial epiphyseal discs.

Fig. 3-C: A roentgenogram, at the age of eleven, showing bony bridging (*a*) of the proximal tibial plate. The central peak of the distal femoral disc now appears as a radiolucent defect (*b*).

horizontal. A radiolucent defect was present in the metaphysis of the femur in the area previously occupied by the central peak of the growth disc. The inequality of the length of the limbs at the age of eleven was six centimeters,—much less than might be expected by a growth arrest occurring near the age of two and secondary to osteomyelitis. The flexion deformity of the right tibia was corrected by osteotomy and the limb-length inequality by shortening of the left femur.

CASE 5. M. J., a girl, had tuberculosis of both hips, and growth arrest of the major epiphyseal discs of both knees developed. Onset of tuberculosis in the left hip was at the age of six, and in the right hip, at the age of seven. Arthrodesis of the left hip was performed at the age of seven. The right hip was not operated upon. Immobilization of both lower extremities in plaster dressings was carried out between the ages of six and nine and one-half. At the age of ten, six months after resumption of weight-bearing, a varus deformity of the left knee was present. Roentgenograms showed angulation of the shaft of the tibia, with proximal overgrowth of the head of the fibula. Both the distal femoral and proximal tibial plates were thin and irregular, although neither was closed. The varus deformity of the shaft of the tibia was corrected by osteotomy of the proximal metaphysis.

Bony ankylosis of the right hip did not occur. At the age of eleven, roentgenograms of the right knee showed thinness and irregularity of both the distal femoral and proximal tibial cartilaginous plates, with bony bridging of the posterior medial quadrant of the proximal tibial plate.

In the following four patients, growth arrest of the proximal tibial epiphyseal plate developed. In each case, the bony bridge was located in the posterior medial quadrant of the cartilaginous disc.

CASE 6. P. O., a girl, aged two, had had tuberculosis of the right hip for nine months. There was a persistently draining sinus. The extremity was immobilized in plaster dressings for four and one-half years. At the age of six and one-half, arthrodesis of the right hip was performed. Further immobilization of the hip in plaster was carried out for one and one-half years. Motion was still present in the hip when immobilization was discontinued. Bony ankylosis of the hip was present one year later, but there was also marked flexion adduction of the femur.

One year after the patient resumed weight-bearing, roentgenograms of the right knee showed closure of the proximal tibial epiphyseal cartilage medially and posteriorly. No alignment deformity of the tibia was present, but the head of the fibula had overgrown proximally. The distal femoral epiphyseal plate was

open, but the disc showed irregularity in its medial portion. Roentgenograms two years later showed flexion and varus deformity of the shaft of the tibia. The bony bridging of the tibial disc was wider. The irregularity, previously noted in the medial half of the distal femoral plate, had disappeared, but longitudinal striations of dense trabeculae were present in this region. Osteotomy to correct the deformity of the tibia was done through the proximal tibial metaphysis. During this operation, the proximal end of the tibia was inspected and no evidence of epiphyseal cartilage was found. The deformity of the tibia did not recur, nor did the distal femoral epiphyseal plate undergo premature closure.

CASE 7. J. G., a boy, aged nine, had had tuberculosis of the left hip for nine months. Operation to produce ankylosis of the hip was done at the age of nine and was repeated at the age of eleven. Plaster immobilization of the extremity was carried out for three years and three months. The patient was ambulatory on crutches, without bearing weight on the affected limb, for an additional year. Bony ankylosis of the hip was never obtained.

Prolonged immobilization was carried out in this patient during the period of rapid growth, and weight-bearing on the affected limb was not allowed until the age of thirteen and one-half. No roentgenographic examination of the knee was made prior to the time of normal epiphyseal maturation. Because of instability of the knee, however, roentgenograms were made at the age of seventeen. The results of an unequal arrest of growth in the proximal tibial plate were shown by the underdeveloped medial tibial tuberosity, the overgrowth of the head of the fibula, and an oblique growth-arrest scar in the proximal tibial metaphysis.

CASE 8. J. P., a girl, aged seventeen, had bony ankylosis of the right hip with marked flexion-adduction deformity of the femur. An alignment deformity of the right knee and a discrepancy of eleven centimeters in limb length were also present. The patient had had a draining sinus in the right hip from the age of four to eight, but she had had no motion in the joint since she was five. She had had no treatment other than several months of bed rest at the onset of the disease. The primary coxitis was assumed to have been pyogenic.

Roentgenograms (Fig. 4) of the right tibia at the age of seventeen showed marked varus and posterior angulation of the proximal metaphysis of the tibia. The lateral view showed marked anterior bowing of the shaft of the fibula and overgrowth of the head of the fibula above the level of the knee joint. The condyles of the femur were rotated posteriorly, indicating that unequal growth arrest had occurred in the distal femoral plate. That growth arrest also occurred in the distal tibial epiphyseal cartilage is indicated by the medial and posterior inclination of the distal tibial articular surface. The deformities of the right lower extremity were corrected by subtrochanteric osteotomy of the femur and multiple osteotomies of the shafts of the tibia and fibula. The inequality in limb length after the osteotomies was corrected by lengthening the right tibia four centimeters and shortening the left femur six centimeters.

FIG. 4

Case 8, J. P. Roentgenograms of right leg, at the age of seventeen, showing varus and posterior angulation proximally in the tibia, overgrowth and bowing of the fibula, posterior rotation of the femoral condyles, and obliquity of the distal tibial articular surface.

CASE 9. M. B., a boy, had acute anterior poliomyelitis at the age of four, which affected the trunk and both lower extremities. After two

FIG. 5-A FIG. 5-B

FIG. 5-C

Case 9, M. B. Roentgenograms of knee and photograph of patient.
Fig. 5-A: At the age of ten, showing bony bridging medially at the tibial cartilaginous disc. Alignment deformity of the knee has not yet developed.
Fig. 5-B: At the age of twelve; tibia vara and proximal displacement of head of fibula are now present.
Fig. 5-C: Photograph at the age of twelve, showing tibia vara and shortening of right tibia.

years, almost complete recovery had occurred in the left lower extremity, but there was residual paralysis of the right hip flexors, glutaeus medius, quadriceps femoris, biceps femoris, and calf muscles. There was internal rotation of the tibia upon flexion of the knee, because of the unopposed pull of the medial hamstring muscles. From the age of six to eight the right limb was supported in a long leg brace. This was discarded after operative stabilization of the foot.

FIG. 6-A

FIG. 6-B

Case 10, L. L. Lateral roentgenogram and photograph, at the age of fifteen, showing anterior angulation of shaft of tibia and genu recurvatum.

At the age of ten, three centimeters of shortening of the right tibia was present. The femora were equal in length. Roentgenograms (Fig. 5-A) revealed bony bridging of the posterior medial quadrant of the proximal tibial epiphyseal plate. Proximal overgrowth of the head of the fibula was evident. An oblique growth arrest line was seen in the proximal metaphysis of the tibia. Roentgenograms (Fig. 5-B) two years later showed increased bony bridging of the tibial disc and proximal displacement of the head of the fibula. Photographs (Fig. 5-C) at the age of twelve showed the inequality of length between the tibiae, and a marked tibia vara deformity was then present. Some flexion of the knee was also present. The deformity was corrected by osteotomy

of the tibia with epiphyseodesis of the anterior lateral portion of the proximal tibial growth disc and excision of the head of the fibula. Examination at the age of fourteen showed no recurrence of the deformity.

Growth arrest occurred in this patient without prolonged immobilization of the extremity. The imbalance of muscle pull at the hip and at the knee probably was an important factor in the development of the growth deformity.

In three patients growth arrest occurred in the anterior portion of the proximal tibial plate. The disability responsible for the growth disturbance started later in childhood in these patients than in the previous cases, in which the growth arrest was located in the posterior medial quadrant of the proximal tibial disc.

CASE 10. L. L., a boy, had had tuberculosis of the right hip at the age of seven. His right lower extremity was at that time supported in a plaster dressing for seven months. One year later the right knee was manipulated under anaesthesia, because of persistent limitation of motion. A supracondylar fracture of the right femur resulted, necessitating further immobilization in plaster for three months. Soon after entry to the Hospital, at the age of ten, arthrodesis of the right hip was done. Bony fusion followed immobilization for another nine months.

When he was thirteen, the patient noticed progressive anterior protrusion of his right patella. A roentgenogram (Fig. 6-A) of the knee at the age of fifteen showed anterior angulation of the shaft of the tibia and proximal displacement of the head of the fibula. The tibial epiphysis was fused to the metaphysis. The distal femoral and proximal fibular discs were still evident. A photograph (Fig. 6-B) at the same age showed the deformity of the right knee. The right lower extremity was ten centimeters shorter than the left. The deformity of the tibia was corrected by wedge osteotomy. The residual inequality of seven centimeters in limb length was corrected later by shortening of the left femur.

CASE 11. V. H., a girl, had had tuberculosis of the right hip since the age of seven. Arthrodesis was done at the age of eleven. Flexion-adduction deformity of the right femur was corrected by a subtrochanteric osteotomy at the age of thirteen. The total period of immobilization in plaster dressings was one year and eleven months. No deformity of the right knee was noted when the patient was discharged at the age of thirteen.

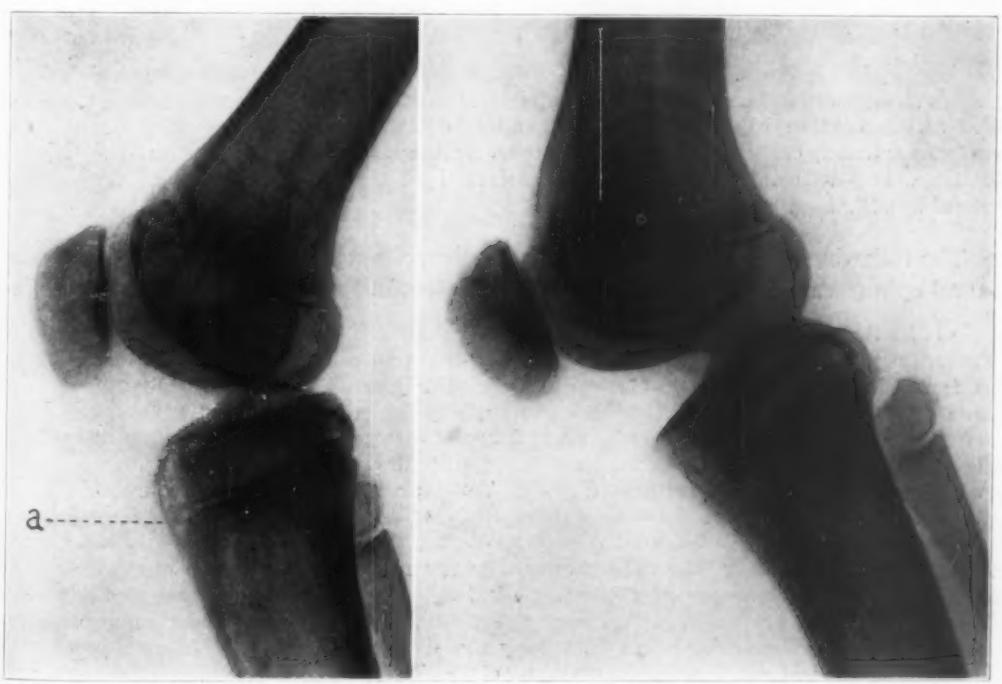

FIG. 7-A FIG. 7-B

Case 12, J. B. Roentgenograms of knee.
Fig. 7-A: At the age of twelve, showing bony bridging (*a*) of anterior aspect of proximal tibial plate.
Fig. 7-B: At the age of fourteen, showing anterior angulation of shaft of tibia.

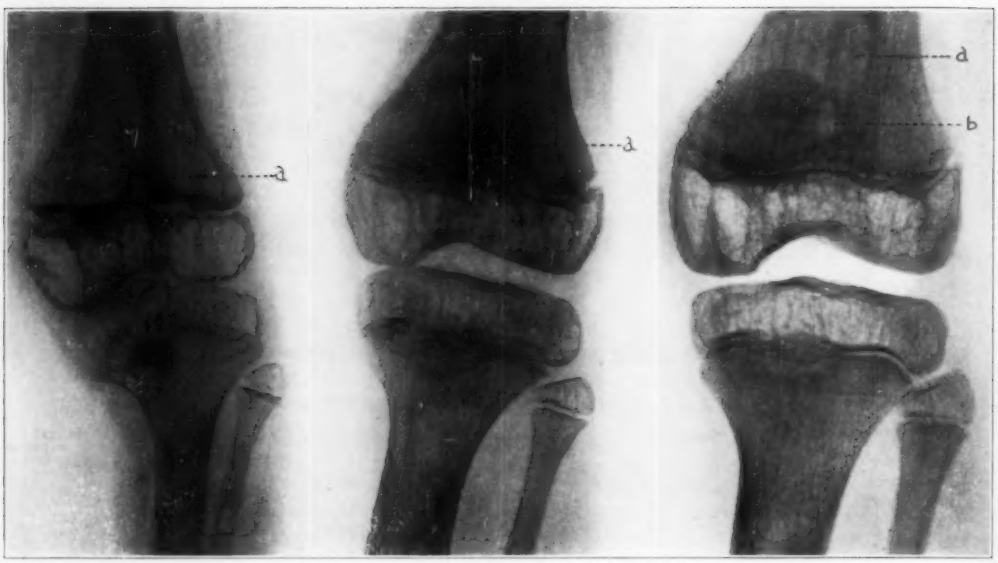

FIG. 8-A FIG. 8-B FIG. 8-C

Case 13, R. Z.

Fig. 8-A: Roentgenogram of knee, at the age of seven, shows irregularity (*a*) of distal femoral plate present after three years' fixation in a plaster dressing.

Fig. 8-B: At the age of eight and one-half, showing this irregularity separating from epiphyseal disc after weight-bearing had been resumed.

Fig. 8-C: At the age of ten, showing radiolucent defect (*a*) left behind in the metaphysis with continued growth; a second defect (*b*) was seen adjacent to the growth cartilage.

Examination at the age of twenty-six showed a marked recurvatum deformity of the right tibia. The patient did not remember the onset of the deformity. Roentgenograms of the right knee showed anterior angulation of the shaft of the tibia and proximal displacement of the head of the fibula.

CASE 12. J. B., a boy, aged eleven, had a marked slipping of the right capital epiphysis of the femur, for which he had been immobilized in plaster for seven and one-half months. Roentgenograms of the knee (Fig. 7-A), taken at the age of twelve, three months after the plaster dressing had been discontinued, showed bony fusion anteriorly of the proximal tibial plate to the metaphysis. A roentgenogram (Fig. 7-B), taken two years later, showed the anterior angulation of the shaft of the tibia which resulted. This deformity was corrected by osteotomy.

The following case demonstrates the evolution of a growth irregularity of the distal femoral epiphyseal cartilage into a radiolucent defect in the distal femoral metaphysis.

CASE 13. R. Z., a girl, aged four, had tuberculosis of the left hip which had been present since the age of three. After plaster immobilization from the age of four to the age of seven, arthrodesis of the left hip was done. Immobilization for ten months followed this operation. Bony ankylosis was complete at the age of eight.

A roentgenogram of the left knee at the age of four showed osteoporosis and shadows of the epiphyseal cartilages which appeared normal. At the age of seven, after three years of immobilization, a roentgenogram (Fig. 8-A) showed evidence of marked growth disturbance at the left knee. Both major epiphyseal cartilages were thin and irregular. The width of the shaft of the tibia was markedly reduced. The subchondral zone of ossification of the distal femoral disc was sclerotic, and the plate had a central peak projecting into the metaphysis. Dense longitudinal trabeculae were present near the posterior medial quadrant of the proximal tibial disc. Premature closure of either or both of these epiphyseal discs might be expected to follow such growth disturbance. However, roentgenograms (Fig. 8-B), taken at the age of eight and one-half, after weight-bearing had been resumed, showed more nearly normal epiphyseal cartilages. No displacement of the head of the fibula was present. The peak at the center of the distal femoral disc was elongated into the metaphysis as a radiolucent defect. In the roentgenogram (Fig. 8-C), at the age of ten, both the proximal tibial and distal femoral discs were open and appeared normal. Two defects were now present in the distal femoral metaphysis,—one adjacent to the posterior aspect of the growth cartilage and another more proximal in the shaft. It may be assumed that the more proximal defect was formed first and had become separated

from the epiphysis by longitudinal growth of the femur. At the age of fourteen, roentgenograms showed fusion of all the growth cartilages. The proximal displacement of the head of the fibula and the medial angulation of the shaft of the tibia indicated that premature fusion of the proximal tibial plate had occurred during the preceding four years.

ROENTGENOGRAPHIC APPEARANCE

Roentgenographic evidence of growth disturbance at the knee is usually present prior to the development of marked inequality of limb length or alignment deformity. It usually is not detected, however, because roentgenograms of the knees of these patients are not made until some factor, such as deformity, calls attention to the knee. By this time there are marked alterations in the epiphyseal cartilages, which represent advanced growth disturbance. The early changes are not observed unless repeated roentgenographic examinations are made from the onset of the disability to the end of the active growth period. In seven patients of this group, such serial roentgenograms were made.

The early alterations of the epiphyseal cartilage, which are evidence of growth disturbance at the knee, are thinness of the epiphyseal disc and the presence of a transverse zone of dense bone on its metaphyseal aspect. Growth-retardation scars are numerous, and osteoporosis of the regional bone is pronounced. The contour of the epiphyseal cartilage is irregular with one or more peaks projecting into the metaphysis. In some instances, radiolucent defects in the metaphysis are further evidence of deranged endochondral ossification (Cases 1, 2, 4, 6, and 13). Such changes may precede actual cessation of growth; but, in some cases, recovery of normal longitudinal growth occurs.

If growth arrest does occur, roentgenograms show a bony bridge across the epiphyseal disc. The transverse zone of bone on the metaphyseal aspect of the disc becomes wider and more dense in the region of this bony bridge, and long trabeculae converge toward its site from both the epiphysis and the metaphysis.

Certain sites are more favorable for epiphyseal bridging. In the distal end of the femur, the point of arrest is commonly posterior to the central portion of the disc. The remaining disc may continue to grow, causing posterior rotation of the condyles. In the proximal end of the tibia, the arrest is often in the posterior medial quadrant, in which case continued growth of the remaining cartilage results in tibia vara. Not infrequently, the tibial tubercle unites prematurely with its metaphysis, and tibia recurvata develops. In either case proximal displacement of the fibula in relation to the tibia occurs.

PATHOLOGICAL FINDINGS

The essential pathological change is degeneration of the epiphyseal cartilage and its replacement by bone. At the site where the plate is bridged, trabeculae of normal character unite epiphyseal and metaphyseal bone. The adjacent portions of the disc show the most marked changes and become thinned, fibrillated, and fissured. Cartilage cells are irregularly placed so that columns are short and disorientated. Transversely, orientated trabeculae cover the metaphyseal surface of the plate. Although the disc may continue some growth away from the point of bridging, its matrix and cartilage cells show some degree of degenerative change. These alterations are demonstrated in Figures 2-D and 2-E.

TREATMENT

Prevention of growth deformity in chronic diseases of the lower extremity is not always possible. However, measures that shorten the duration of disability from hip disease (such as operative fusion), avoidance of prolonged immobilization, and careful supervision of the patient who resumes weight-bearing on a limb which has undergone marked osteoporosis, may minimize the chance of growth arrest. If arrest does occur, early recognition may make it possible to avoid deformity or marked discrepancy in limb length by the employment of an epiphyseal-arrest operation. There is no way to produce resumption of normal growth from a cartilaginous disc which has undergone partial or

complete fusion. If asymmetrical growth arrest has occurred, alignment deformity must be prevented by producing surgically a complete arrest of growth in that epiphysis. Employment of the growth-arresting operation on the normal limb to produce eventual equalization of limb length depends upon the amount of shortening present and the amount anticipated when skeletal growth is complete. In patients whose skeletal growth is complete, equalization of limb length may be obtained by femoral shortening on the normal side, sometimes by lengthening of the short limb, or occasionally by a combination of both.

DISCUSSION

Atrophy of disuse accompanies any prolonged disability of an extremity, and during the growth period it affects the epiphyseal cartilage as well as the other tissues in the limb. Although osteoporosis becomes evident a short time after the onset of the disability, the epiphyseal discs appear normal in roentgenograms until the disability has been present for a prolonged period. The thinness and irregularities of the disc, and the dense transverse plate of bone which is then present on its metaphyseal aspect, give the disc an appearance similar to any epiphyseal cartilage at the time of its normal maturation. Radiolucent defects in the metaphysis and peaks of epiphyseal cartilage projecting into the metaphysis may also be present at this time. These latter changes, however, are not observed in normal closure of the epiphyses, and are difficult to explain adequately. The peaks probably represent areas of localized growth retardation in the epiphyseal cartilage, and are left behind in the metaphysis with the continued growth of the less affected portions of the plate. On the other hand, the dense transverse plate of bone which forms on the metaphyseal aspect of the cartilaginous disc with growth retardation may inhibit the circumferential increase in the size of the epiphysis, and thus cause the growing plate to buckle. The apex of these peaks would be a favorable site for the first appearance of growth arrest, but in several patients in this report (Cases 4, 6, and 13), the apex of the peaks seemed to break off and form a radiolucent defect in the metaphysis. Thus, the defect would represent an epiphyseal-cartilage rest, an unwarranted assumption without a biopsy. In Case 13, one such defect formed in the femur and was displaced into the metaphysis by longitudinal growth. A second, more distal, defect then formed. It is more likely that the defects consist of fibrous tissue. They have roentgenographic similarity to the early appearance of the lesion described by Jaffe as a non-ossifying fibroma and by Hatcher as a metaphyseal fibrous defect. The defects disappeared with subsequent growth of the bone.

Although the growth-retardation changes discussed above are more pronounced at the more rapidly growing epiphyseal plate at the distal end of the femur, actual premature closure was observed more frequently at the proximal end of the tibia. As the osteoporosis disappeared with active use of the limb, the epiphyseal discs frequently assumed a more normal appearance, and the inequality of limb length did not increase. In most patients with tuberculosis of the hip, several years elapsed between the discontinuation of plaster fixation of the extremity and the occurrence of growth arrest. These observations indicate that, while atrophy of disuse may cause partial degeneration of epiphyseal cartilage and growth retardation, it alone does not cause growth arrest.

Growth arrest occurs when the epiphysis and the metaphysis are united by a bony bridge across the epiphyseal plate. Gill had suggested that this bridge forms as a result of a rupture of the epiphyseal disc when the normal support of the disc collapses with fracture of the adjacent atrophied trabeculae. Fracture across an epiphyseal plate does frequently result in growth arrest. However, it seems unlikely that this is the only explanation of the growth arrest in these patients, since the growth arrest would be detected soon after plaster immobilization has been discontinued, while osteoporosis is most pronounced. Also, elastic cartilage resists fracture better than atrophic bone does.

An alternate explanation of the growth arrest in these cases is that the already par-

tially degenerated cartilage is unable to withstand the abnormal stresses of a faulty gait. The cartilage wears through at the point of greatest stress and allows bony union of the epiphysis and metaphysis. In favor of this is the high incidence of growth arrest in the posterior medial quadrant of the proximal tibial plate, and the fact that growth arrest never occurred in the fibula, which is unimportant in weight-bearing.

CONCLUSIONS

1. Growth arrest may occur at the knee as a complication of chronic disability of the lower extremity.

2. Growth retardation of the epiphyseal discs precedes permanent arrest. This retardation is due to partial degeneration of the cartilage as the result of atrophy of disuse.

3. Arrested growth occurs later, due to complete degeneration of a portion of the epiphyseal plate and the repair of the defect so formed by a bony bridge.

4. This complete degeneration is probably due to some secondary factor, such as the abnormal stresses present with a faulty gait.

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INTERNAL CONTACT SPLINT

DISCUSSION

(*Continued from page 52*)

of fixation and present it to this Academy, since I believe he has made a very definite contribution to the treatment of fractures by internal fixation.

DR. G. W. N. EGGERS (closing): When one has been following plate immobilization of fractures for a period of years, only a firm conviction of its failure turns one to another method, especially when this method is diametrically opposed to past teachings. The first case requires a little courage, and after that it is simplicity itself. As to the shearing force, it is decreased by the use of a long splint. Complete immobilization is not necessary in the treatment of fractures, but we should endeavor to accomplish physiological stability. I do not use a screw placed obliquely across the fragment ends, because the longitudinal muscle pull locks the fragments sufficiently to hinder rotation. It simplifies the technique to use only four screws, placed at chosen points in the fragments, instead of in the holes dictated by a plate.

HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS *

BY COLONEL ROBERT I. HARRIS, M.C., AND MAJOR THOMAS BEATH

Royal Canadian Army Medical Corps

It may appear strange that there is any necessity to discuss such a common and apparently simple entity as flat-foot. The explanation is that the problem of pes planus is not simple, but in reality is complex and obscure. The configuration and the function of the foot are determined by the interplay of many factors. Even today, we know all too little of the nature and the mode of action of these forces. Attempts to advance our knowledge of the subject are handicapped by lack of material for the study of foot function in relation to structure. In the autopsy room, feet are not commonly the subject of study. Even in the anatomical museum, where abundant material for the study of structure is available, knowledge is lacking of function during life, to correlate with changes in structure which may be present. It is not surprising, therefore, that the accumulation of accurate knowledge regarding foot problems has been slow.

The purpose of this paper is to report certain recent observations regarding flat feet, and particularly to discuss the relationship between the architecture of the tarsus in severe flat-foot and the impairment of function resulting therefrom.

Not all feet which are flat are the cause of serious incapacity. On the other hand, great disability does arise from certain types of flat-foot. Flat feet are not all alike, either in their causation or in their deformity. Indeed, the term "flat-foot" is used somewhat loosely to describe all foot deformities characterized by lowering of the longitudinal arch. This condition may result from various causes. It becomes important, therefore, to distinguish from each other the various types of flat-foot and to determine the cause of each.

During 1944 and 1945, the Royal Canadian Army Medical Corps conducted an extensive survey into Army foot problems, which included the careful and detailed examination of the feet of 3 600 recruits, and the subsequent re-examination during training of those who enlisted. During the course of this survey, which revealed a representative cross section of the foot problems of young men, it became evident that pes planus must be divided into at least three varieties: (1) the severe and disabling type discussed in this paper; (2) peroneal spastic flat-foot, also gravely incapacitating; and (3) simple depression of the longitudinal arch. In contrast to the first two, this third type is of little consequence as a cause of disability. The low arch in such cases may be regarded as the normal contour of a strong and stable foot, rather than the result of weakness in foot structure or weakness of the muscles which motivate the foot.

We are concerned here with the severe and disabling type of flat-foot, mentioned first in the preceding paragraph. Because of clinical characteristics which will be discussed, we have applied to it the descriptive title of "hypermobile flat-foot with short tendo achillis". This new, elaborate, and somewhat cumbersome title is not intended to suggest that we are describing a new variety of flat-foot, hitherto unrecognized. It is used because it describes the chief clinical features of the syndrome, and also because it emphasizes the necessity of recognizing different types of flat feet which must be distinguished from one another. Hypermobile flat-foot with short tendo achillis ("HFF-STA") is one such variety which presents distinctive clinical features, the result of alterations in the relationship of the talus to the calcaneus.

This type of flat-foot is the common form of severe pes planus in childhood and young adult life. Many authors have recognized and described its various clinical manifestations, especially the short tendo achillis. No one, as far as we can ascertain, has appreciated it as

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1946.

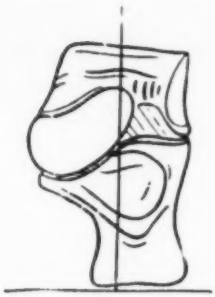

FIG. 534.—The relation of the astragalus to the os calcis.

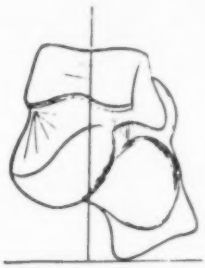

FIG. 535.—The relation of the astragalus and os calcis in flat-foot.

FIG. 1

Diagrams illustrating Whitman's conception that, in flat-foot, the head of the talus is displaced inward and downward in relation to the calcaneus. Whitman implies that this is the *result* of the flat-foot deformity, rather than the *cause*, as is actually the case. (*Reproduced, by permission of Lea and Febiger, from* A Treatise on Orthopaedic Surgery, *by Royal Whitman, Ed. 5, 1917, p. 694.*)

a clinical entity, based upon a specific structural relationship of the talus to the calcaneus. Such new knowledge as can be contributed by this paper is related to the demonstration of this fact.

Royal Whitman described well many of the clinical features of this type of flat-foot, and illustrated with diagrams (Fig. 1) his conception of the changed relationship of the talus to the calcaneus in flat-foot. Although his conception is not based upon anatomical or roentgenographic observations and is regarded by him as the *result* of the deformity, it closely resembles the structural deviation which we have observed in our patients, and believe to be the *cause* of the deformity. Hibbs, in 1914, apparently was describing this type of foot in children, although he placed the whole emphasis upon the short tendo achillis. Certain German authors, including Schultze and Gocht, have advocated lengthening of the tendo achillis in the treatment of severe flat-foot. They seem to have been treating the type of flat-foot described in this paper, with emphasis upon the short tendo achillis.

Hoke described this type of flat-foot well in 1931, but his mistaken conception that muscle power plays the all-important role in maintaining the shape of the foot led him to the false conclusion that navicular-cuneiform fusion will most simply correct the condition by providing a longer lever through which the muscles may exert their power. By his operation, some improvement is obtained by the lengthening of the tendo achillis, but the fundamental structural weakness is unaffected. In our hands, Hoke's operation for flat-foot has been disappointing.

CLINICAL MANIFESTATIONS OF HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

Hypermobile flat-foot with short tendo achillis presents distinctive features which are so characteristic as to render its recognition easy in well-marked cases.

History

Since this type of flat-foot is based upon a congenital anomaly of structure of the talus and the calcaneus, the resulting deformity appears early in life. Many cases, and perhaps all, become manifest in childhood by the observation of an alert parent that there is flatness of the feet. He is the more likely to be aware of his child's deformity, since he himself may suffer from the same condition; there is a strong tendency for it to be inherited. For a varying period of time the deformity does not produce symptoms, but sooner or later appear pain and aching in the feet and fatigue on standing or walking. Symptoms may be evident as early as five years of age, but they more commonly appear

in the early teens. From the time of the first appearance of symptoms, there is a history of constant foot disability and limited capacity for foot effort. The child learns to avoid strenuous sports and heavy activities, and by this means adjusts himself to a regimen of activity which falls within the limitations imposed by his disability. The characteristic history, therefore, is one of flat-foot since childhood with some degree of incapacity,

FIG. 2

Hypermobile flat-foot with short tendo achillis. The foot is not deformed unless it is bearing weight. This can best be demonstrated by seating the patient on the edge of a table and permitting his legs and feet to dangle from the knees, completely free of superimposed weight.

FIG. 3

Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). When weight is borne upon the foot, the position of well-marked flat-foot is assumed.

FIG. 4

FIG. 5

Fig. 4: Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). The deformity can be corrected effectively by muscular effort, if the patient stands on his tiptoes.

Fig. 5: Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). When the patient stands with heels on the floor, the deformity can still be corrected by muscular effort, although less easily and less well. Note the use of the long toe flexors to accomplish correction.

observed first in late childhood or early adolescence and continuous and increasing since then. It should be emphasized, however, that the disability in youth usually is not so great as might be expected from the degree of flatness of the feet; also that there are wide variations in the basic abnormality and consequently wide variations in the severity of the deformity and in the degree of functional incapacity.

Feet Flat only on Weight-Bearing

In typical cases, the flatness of the feet is manifest only when the patient bears weight. When weight is completely removed from the feet, they assume a shape which seems normal (Fig. 2). When the feet are placed on the floor and weight is borne upon them, they assume a marked degree of pes planus of a characteristic type (Fig. 3).

The disappearance of flatness when the feet are relieved of weight, and its reappearance when weight-bearing is resumed, constitute evidence of the mobility of the feet and of the action of the short tendo achillis.

The patient usually can correct the deformity by voluntary muscular effort. He does so best if he stands on tiptoe (Fig. 4), since this eliminates the effect of the short tendo achillis. If the heels are on the ground, he can still correct the deformity by muscular effort, although with difficulty and only with the assistance of accessory muscles (Fig. 5). The statement frequently is made that flat feet which are capable of correction by muscular effort cause little functional incapacity. Such is not the case with hypermobile flat-foot with short tendo achillis which, in spite of its mobility and capability of correction by muscular effort, is the source of great disablement.

Shortness of Tendo Achillis and Limitation of Dorsiflexion at Ankle Joint

If movement at the ankle joint is examined carefully, it can be demonstrated that its range in dorsiflexion is greatly limited. To obtain comparable results with this test, it is necessary that the knee be fully extended while movements of the ankle joint are tested; otherwise variations in the tension of the gastrocnemius will modify the range of dorsiflexion at the ankle. It is equally important to ensure that only movement at the ankle joint is permitted. For this purpose, movement at the subtalar and mid-tarsal joints must be eliminated by the manner in which the foot is held (Fig. 6). When examined with

careful observance of these details, the hypermobile flat foot with short tendo achillis displays a remarkable limitation in the range of dorsiflexion at the ankle (Fig. 7). This never reaches a right angle and frequently falls short of it by as much as 25 degrees (that is, the angle of greatest dorsiflexion is 115 degrees). In normal feet, the angle of greatest dorsiflexion may reach 20 degrees beyond the right angle (that is, the angle of greatest dorsiflexion is 70 degrees).

This limitation of dorsiflexion at the ankle joint is due to shortness of the triceps surae

FIG. 6

Manner of examining the foot to determine the limit of dorsiflexion at the ankle joint. The knee is fully extended; the foot is held in such a manner as to eliminate movement of the subtalar and mid-tarsal joints; only ankle-joint movement is permitted. It can then be demonstrated that the foot fails to reach a right angle because of the shortness of the tendo achillis. (Same case as illustrated in Fig. 2.)

FIG. 7

Shortness of the tendo achillis in hypermobile flat-foot. In this case, the foot fails by 30 degrees to reach a right angle.

FIG. 8-A FIG. 8-B

FIG. 9

Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). Illustrating the various elements in dorsiflexion of the fore part of the foot.

Fig. 8-A: Up to the point shown, the movement takes place at the ankle joint, and the foot remains normal in shape.

Fig. 8-B: Further dorsiflexion of the fore part of the foot is accomplished by upward and outward swing of the fore part of the foot, which occurs at the mid-tarsal and subtalar joints and is associated with the development of the deformity of flat-foot.

Fig. 9: Double-exposure photograph, to illustrate the features described in Figs. 8-A and 8-B.

(gastrocnemius and soleus, plus the tendo achillis). It should be noted that the phrase "with short tendo achillis" is used to indicate shortness of the whole plantar-flexing mechanism of the foot. Furthermore, the term does not imply that the short triceps surae is the *cause* of this type of flat-foot, but merely that it is a characteristic part of the clinical picture. The basic cause lies in the structure of the talus and calcaneus, and possibly also in the hypermobility of the tarsal joints. The shortness of the tendo achillis probably develops because the structure of the foot and the laxity of the tarsal joints deprive it of tension stresses, which normally in youth would facilitate its elongation.

Hypermobility of Subtalar and Mid-Tarsal Joints

The limitation of dorsiflexion at the ankle joint is concealed, and on casual observation may be overlooked, because of another and equally characteristic feature of hypermobile flat-foot with short tendo achillis,—namely, an undue laxity and an abnormally increased range of mobility at the subtalar and mid-tarsal joints (talocalcaneal, talocalcaneonavicular, and calcaneocuboid joints). Normal movement in these related tarsal joints is complex, but the separate elements combine to permit inversion and eversion of the foot. All elements of this complex movement are greatly increased in range in the type of flat-foot under discussion, particularly abduction of the fore part of the foot and dorsiflexion at the mid-tarsal joint. Because of this greatly increased range of movement at the subtalar and mid-tarsal joints, the fore part of the foot can swing upward and outward to an unusual degree (Figs. 8-A and 8-B), but it accomplishes this by an associated valgus of the heel, bulging of the inner margin of the foot, and relative depression of the head of the talus. The increase in the sweep of the foot upward and outward is sufficient to permit the heel to come down on the ground in spite of the short tendo achillis. Upward movement (dorsiflexion) of the fore part of the foot, therefore, consists first of dorsiflexion at the ankle joint, to which is added an upward and outward swing which takes place at the mid-tarsal and subtalar joints, accompanied by valgus of the heel and bulging and depression of the medial margin of the foot. Up to the limit of dorsiflexion at the ankle joint, the foot can

FIG. 10

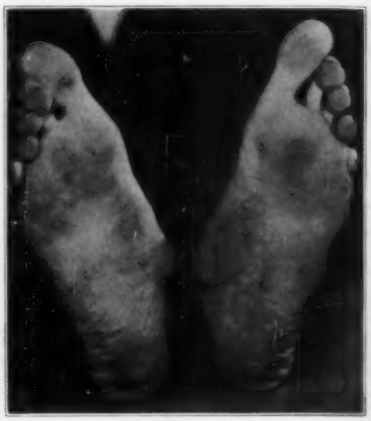

FIG. 11

Fig. 10: Shows the characteristic deformity of severe hypermobile flat-foot with short tendo achillis.
Fig. 11: Severe hypermobile flat-foot with short tendo achillis (same case as Fig. 10). The head of the talus projects prominently on the medial margin of the foot, and is depressed to such a degree that it reaches the floor.

remain normal in shape; but as soon as this limit has been reached, further dorsiflexion of the fore part of the foot, necessary to permit the heel to reach the ground, can only be accomplished by a movement which at the same time breaks the foot medially at the mid-tarsal joint and produces flat-foot.

Instability of the Subtalar and Mid-Tarsal Joints

A further clinical characteristic of hypermobile flat-foot with short tendo achillis is the instability of the subtalar and mid-tarsal joints. Upon examination of the range of dorsiflexion at the ankle joint, it is not easy to eliminate movement at the subtalar and mid-tarsal joints because, with every attempt to dorsiflex the foot at the ankle, the fore part of the foot tends to "flip out" into valgus. There is only one narrow segment in its arc of lateral movement in which pressure against the ball of the foot produces only movement at the ankle joint. So precise is the position in which the foot must be maintained to limit movement to the ankle joint, that the slightest shift to one side or the other permits the fore part of the foot to slip off its point of balance, either medially or laterally (usually the latter). It feels as though it were balanced on a point centered on the head of the talus. If it is maintained in exactly the correct position, considerable force can be applied to the ball of the foot. When the point of balance is lost, the fore part of the foot suddenly slips out and up through its whole range of movement, without any resistance until the limit of valgus has been reached (Fig. 9).

Characteristics of the Deformity

The flat-foot deformity is severe and of a distinctive type (Figs. 10 and 11). Although familiar to everyone who deals with foot problems, it is worth recording here in detail. The fore part of the foot is swung out in relation to the hind part so that their long axes meet at an obtuse angle, the apex of which is medial. The general position of the foot is one of external rotation in relation to the leg. Since the feet most often are placed so as to point forward, this relationship is manifested by internal rotation of the leg in relation to the foot. The head of the talus is thrust downward and inward, producing the bulge which is the apex of the angle between the fore part of the foot and the hind part. Sometimes it is depressed so far that it actually reaches the ground. The calcaneus is tilted into valgus. The lateral malleolus is buried in the laterally displaced foot; the medial malleolus projects prominently, together with the head of the talus. The whole of the sole of the foot is in contact with the ground and, if foot imprints are made which record the distribution of

weight, it can be demonstrated that weight is distributed nearly uniformly throughout the whole area in contact with the ground (Fig. 12).

Variation in the Degree of Deformity

As might be expected from its origin in a congenital anomaly of structure, this type of flat-foot varies in degree of severity. Every gradation of the deformity can be found in a series, from the mildest case, which might not easily be recognized except by one familiar with the lesion, to the most extreme deformity, such as that shown in Figures 10 and 11. This tremendous variation in the degree of deformity is one of the striking features of the syndrome, and one which makes the problem complex: First, it makes the diagnosis of the mild cases difficult; the severe degrees are easy to recognize, but at the other end of the scale, the lesion shades off by imperceptible gradations into the manifestations of a normal foot. Second, it makes assessment of function difficult. To recognize that hypermobile flat-foot with short tendo achillis exists, does not automatically permit an assessment of function. That depends upon the degree of deformity. Third, it renders treatment complex, since the severe degrees require treatment radically different from that needed for the mild cases.

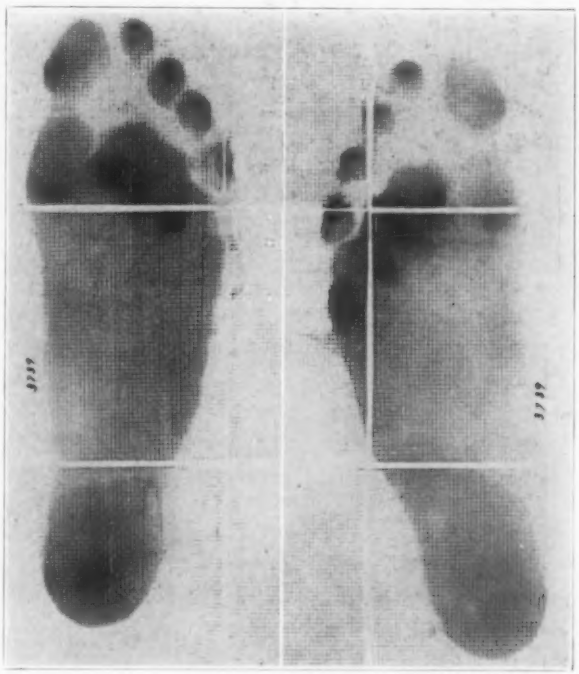

FIG. 12

Footprints of hypermobile flat-foot with short tendo achillis of moderately severe degree (same case as illustrated in Fig. 2).

Recognition of the existence of this condition marks merely the beginning of a complex problem in management, which is modified profoundly by the degree of deformity which is present.

The natural tendency of the deformity to become more severe and certainly more incapacitating with increasing age should also be noted. In childhood, disability is slight. It may not manifest itself until adolescence. In young adult life, with the burden of increasing weight and strenuous activities, it becomes more troublesome, and by middle life it may have reached severe proportions.

Incidence

The incidence of severe hypermobile flat-foot with short tendo achillis is not very high,—about one case in every 145 men examined. The mild form of this condition is nearly eight times more frequent. The incidence of the various types of flat-foot among 3,619 Canadian soldiers was as follows:

Severe hypermobile flat-foot with short tendo achillis	25
Mild hypermobile flat-foot with short tendo achillis	192
Peroneal spastic flat-foot	74
All other cases of low arch	524

ANATOMICAL FEATURES

The peculiar clinical features of this type of flat-foot suggest that its cause may lie in

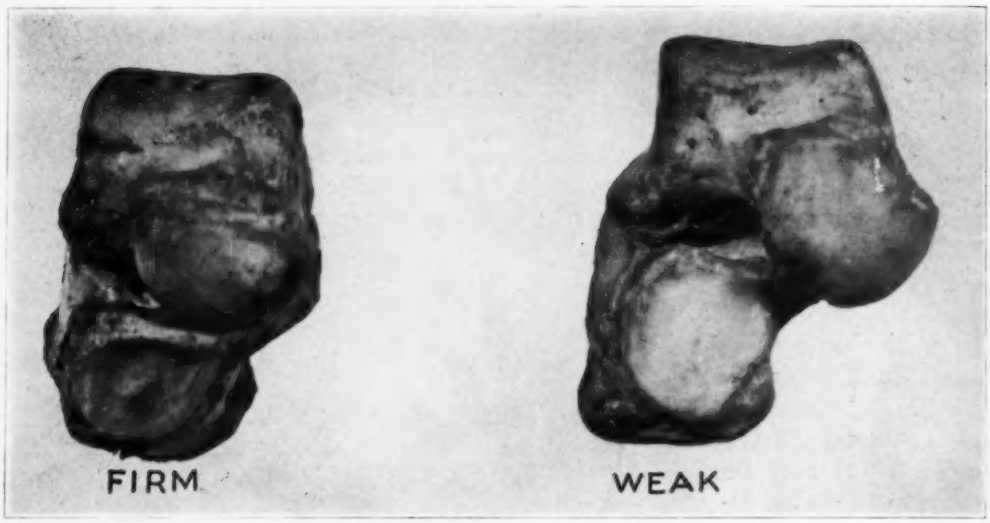

FIG. 13

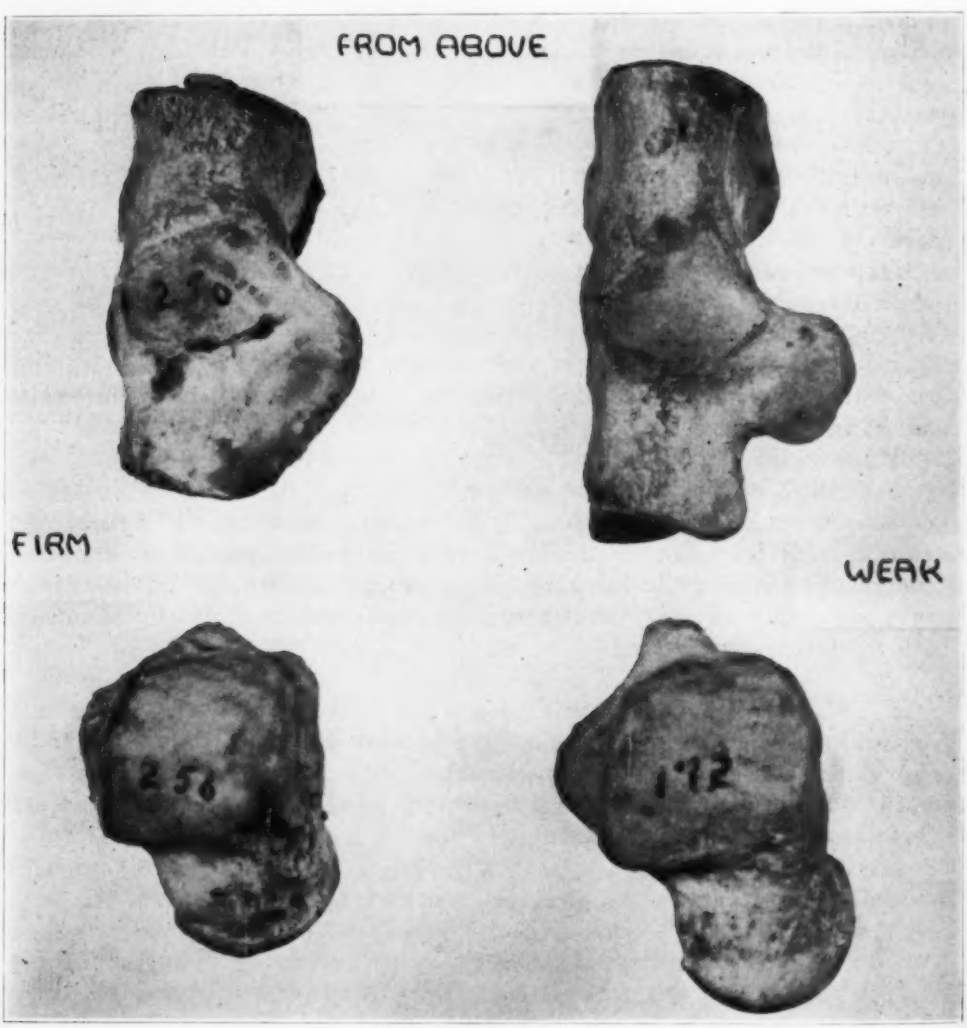

FIG. 14-A

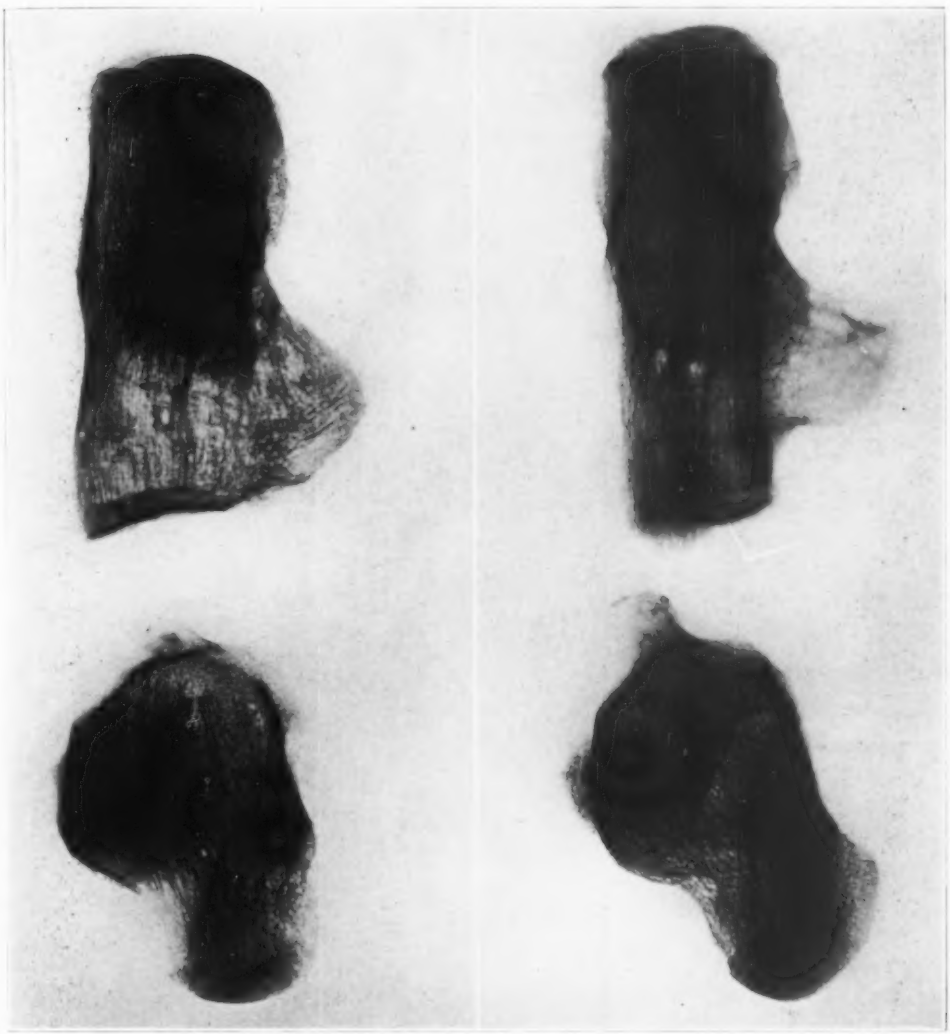

FIG. 14-B

Fig. 13: Anterior view of anatomical specimens which illustrate the extremes of firm and of weak support of the head of the talus by the anterior end of the calcaneus, observed in the examination of the feet of 200 cadavera.

With *firm* support, the center of the head of the talus lies nearly over the center of the anterior end of the calcaneus and nearly flush with it.

With *weak* support, the center of the head of the talus lies far medial to the center of the anterior end of the calcaneus. The head of the talus projects forward from the anterior end of the calcaneus. There is no contact between them, no articulation, and no support.

Figs. 14-A and 14-B: Photograph (Fig. 14-A) and roentgenogram (Fig. 14-B) of the anatomical specimens illustrated in Fig. 13, now disarticulated and viewed from above.

With *firm* support of the head of the talus, the sustentaculum tali is broad, rounded, and runs forward to the anterior margin of the calcaneus. The articular facet on the anterior margin of the calcaneus is continuous with the sustentaculum tali.

With *weak* support of the head of the talus, the sustentaculum tali is a narrow tongue-like process, springing from the medial side of the calcaneus far back, and from a narrow base. No facet is present at the anterior end of the calcaneus for the head of the talus.

some abnormal relationship of the talus to the calcaneus. It is difficult, otherwise, to visualize a mechanism which will permit such a great upward and outward swing of the fore part of the foot. Through the courtesy of Professor J. C. B. Grant and the interest of Professor H. A. Cates of the Department of Anatomy of the University of Toronto, studies of the tarsal bones were undertaken by Professor Cates. The studies revealed wide

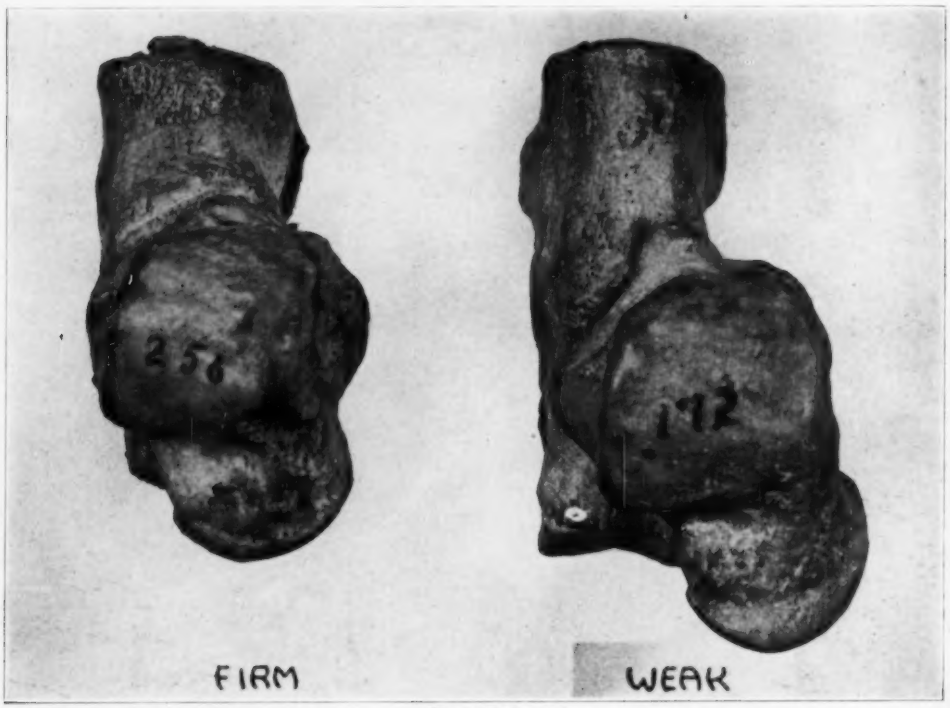

FIG. 15-A

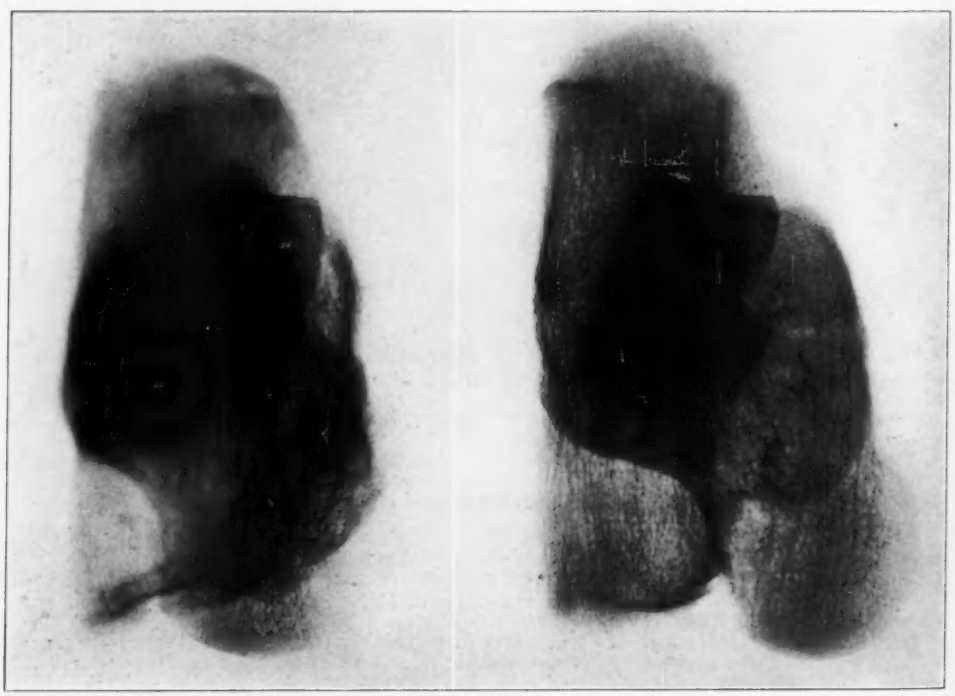

FIG. 15-B

Photograph (Fig. 15-A) and roentgenogram (Fig. 15-B) of the anatomical specimens illustrated in Fig. 13, now articulated and viewed from above.

Firm Support of Head of Talus: The head and neck of the talus are short and thick. The head of the talus is superimposed upon the anterior end of the calcaneus. The calcaneus tends to be short and thick.

Weak Support of Head of Talus: The head and neck of the talus are elongated and project forward beyond the anterior end of the calcaneus. The head of the talus lies anterior and medial to the anterior end of the calcaneus, and is not superimposed upon it.

variations in the relationship of the talus to the calcaneus, especially with reference to the manner in which the head of the talus is supported by the anterior end of the calcaneus. Since the weight of the body is transmitted in considerable part through the head of the talus, the manner of its support will greatly influence its range of movement and its position under stress; and the manner in which it is interlocked in the tarsus will influence the range of movement of the more distal tarsal bones.

Figures 13 to 16-B illustrate four different views of two sets of tali and calcanei. These were selected from the foot bones of 200 cadavera in the Department of Anatomy, University of Toronto, to illustrate the extremes, within this group, of good support and of poor support of the head of the talus by the anterior end of the calcaneus. From the photographs and the roentgenograms of these specimens, certain features can be observed which

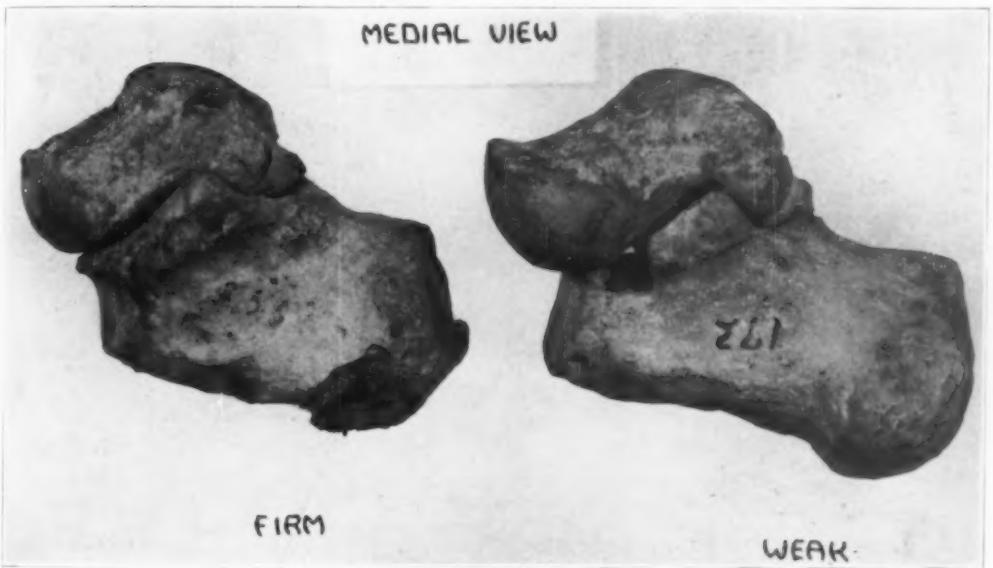

FIG. 16-A

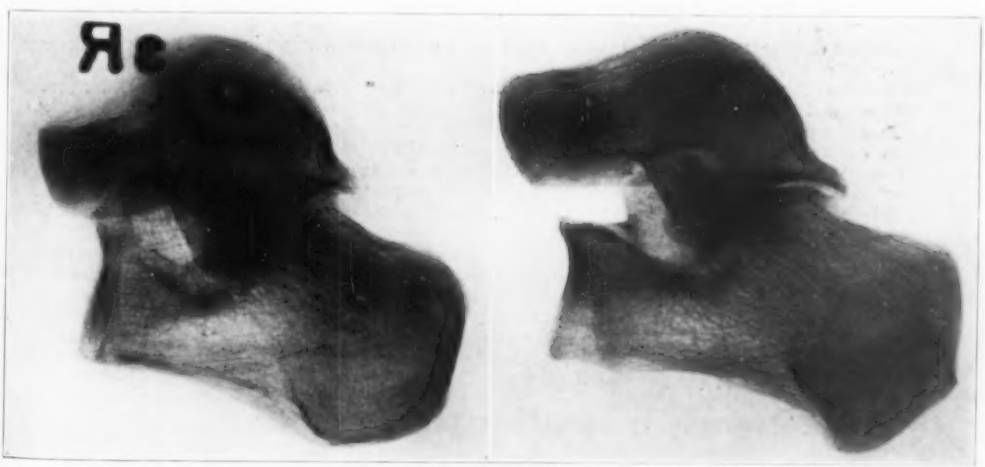

FIG. 16-B

Photograph (Fig. 16-A) and roentgenogram (Fig. 16-B) of the medial view of anatomical specimens illustrated in Fig. 13.

Firm Support of Head of Talus: The head of the talus is supported by an articular surface, which is continuous from the sustentaculum to the anterior margin of the calcaneus.

Weak Support of Head of Talus: There is no facet in this specimen between the anterior end of the calcaneus and the head of the talus. The sustentaculum is narrow and supports the neck only, far back.

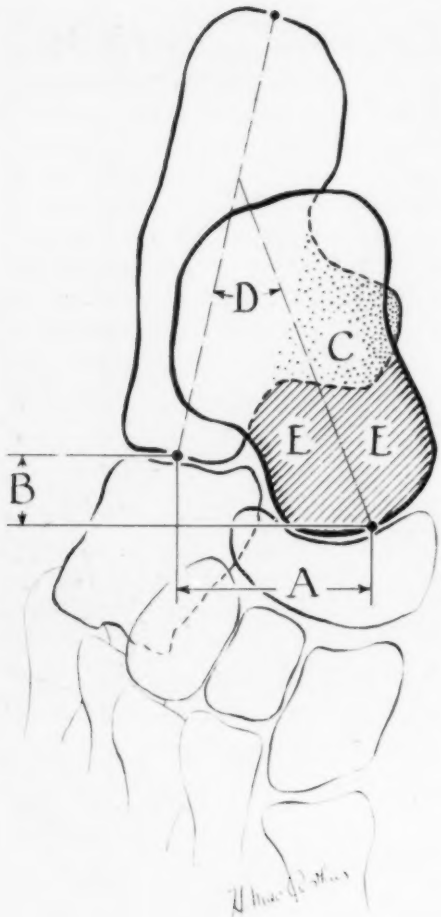

FIG. 17

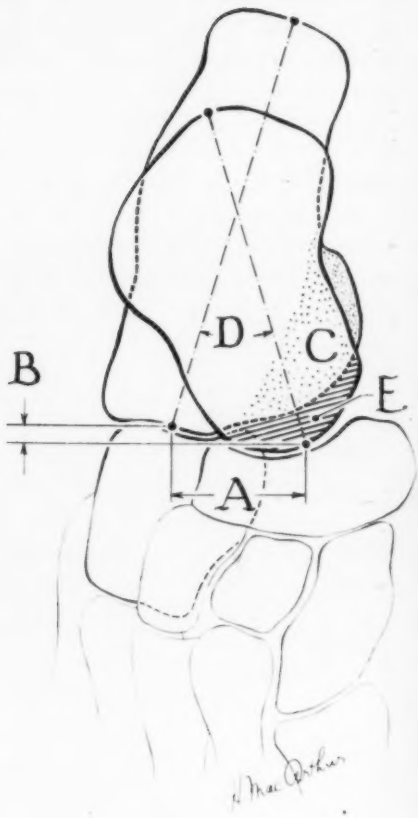

FIG. 18

Fig. 17: Tracing from a standardized roentgenogram, to indicate the various measurements which yield information regarding inadequate support of the head of the talus by the anterior end of the calcaneus.

A: Medial displacement of the head of the talus,—the amount of which is a rough measure of the severity of the clinical picture.

B: Anterior projection of the head of the talus, which brings it farther forward than the anterior end of the calcaneus.

C: Position and shape of sustentaculum. It springs from the medial side of the calcaneus, some distance back from the anterior end and from a narrow base. Its shape is tongue-like. There is an abrupt angle where it joins the calcaneus. The anterior margin of the sustentaculum does not run forward to support the head of the talus. It provides support only to the neck of the talus.

D: Divergence of the long axis of the talus from that of the calcaneus. This is greater than in a normal foot.

E: Extent of the shadow of the head and neck of the talus, which is not imposed upon the shadow of the underlying calcaneus. Several of the preceding factors (medial displacement of the head of the talus, anterior projection of the head of the talus, and shape of the sustentaculum) result in a greater-than-normal area of the head of the talus lying free of underlying calcaneus. The roentgenogram projects this as a shadow of the head of the talus, not imposed upon the shadow of the calcaneus. The extent of this free shadow of the head of the talus becomes a useful index of the degree of inadequate support of the head of the talus.

Fig. 18: Tracing from a standardized roentgenogram of a foot, showing good support of the head of the talus by the calcaneus. (For contrast with Fig. 17.)

are described in the legends accompanying the illustrations. Those features shown in the example of weak support of the head of the talus are important, since it has been possible to reveal, by means of roentgenograms, similar structural relationships in the authors' cases of hypermobile flat-foot with short tendo achillis with such constancy that we believe them to be the basic cause of this type of flat-foot.

The differences demonstrable in the anatomical specimens indicate that wide varia-

FIG. 19

Features of weak support of head of talus by anterior end of calcaneus, as illustrated by the standardized roentgenogram of the case illustrated in Fig. 2. Note that the head of the talus is displaced medially and is far forward. The sustentaculum springs from the body of the calcaneus, far back and at an abrupt angle. There is a large area of the head of the talus which is unsupported by the calcaneus. Compare with Figs. 17 and 18. The footprint of this patient is shown in Fig. 12.

tions exist in the support which is given to the head of the talus by the anterior end of the calcaneus. The head of the talus may be placed solidly upon the calcaneus and everywhere in contact with it, and so firmly supported that superimposed weight will not shift its position. This is illustrated by the example of firm support. On the other hand, the head of the talus may lack completely any contact with the anterior end of the calcaneus and, in addition, it may be displaced so far medially that, under load, there must be an inevitable tendency for it to be thrust downward and for the calcaneus to be tilted into valgus. In the example of weak support of the talus, the absence of any anterior facet leaves the talus supported only by the sustentaculum, and this is so far back as to provide only the most precarious support.

Examination of the specimens cannot but suggest that weak support of the head of the talus is the cause of hypermobile flat-foot with short tendo achillis. The medially displaced head of the talus, without underlying bony support, can be maintained in position only by muscular and ligamentous support. It is incomparably less stable than a talus which is based firmly upon the underlying calcaneus. It is easy to believe that weight-bearing from childhood would cause such a talus to be pushed downward and inward, while the fore part of the foot twists upward and outward.

ROENTGENOGRAPHIC STUDIES

In order to explore the possible relationship between weak support of the head of the talus and hypermobile flat-foot with short tendo achillis, roentgenographic technique was evolved by means of which uniform, standard supero-inferior, lateral, and oblique projections were obtained, of such a quality as to produce an equally good image of all of the bones of the foot [8]. The feet of 3,619 young Canadian soldiers were x-rayed by this

technique, and the standardized films so obtained were studied and correlated with clinical findings and with functional capacity, as judged by performance under the stress of military training. With the extensive experience gained in the Canadian Army Foot Survey, we can state that such roentgenograms are a valuable means of studying the structure of the foot and of correlating it with deformity and with function.

In general, the findings of this study demonstrate that there is a close parallelism between weak support of the head of the talus (as demonstrated by the standard roentgenograms) and the presence of hypermobile flat-foot with short tendo achillis. The roentgenographic evidence of weak support of the head of the talus is nearly always present in this condition, and its degree corresponds closely to the severity of the clinical picture. *The authors believe that inadequate support of the head of the talus is the important basic cause of hypermobile flat-foot with short tendo achillis.*

Roentgenographic Evidence of Weak Support of the Head of the Talus

The standardized roentgenograms were closely comparable to the roentgenograms of the anatomical specimens, so that the structure of the foot could be interpreted from study of the anatomical specimens. The important points indicating weak support of the head of the talus, which can be determined from the supero-inferior roentgenograms, are illustrated diagrammatically in Figure 17.

Figures 19, 20, and 23 show the roentgenographic appearance, in the supero-inferior projection, of feet displaying weak support, average support, and firm support of the head of the talus.

Roentgenograms can never replace clinical examination in the diagnosis of hypermobile flat-foot with short tendo achillis. The value of roentgenographic studies lies in the

FIG. 20

Features of average support of head of talus, as seen in the standardized roentgenogram. Compare with Figs. 17, 18, and 19.

FIG. 21

FIG. 22

Fig. 21: Imprint of the feet illustrated in Fig. 20. There is average support of the head of the talus, and no depression of the arch.

Fig. 22: Imprint of the feet illustrated in Fig. 23. Mild claw-foot is manifested by the high arch and localized pressure under the heads of the metatarsals.

FIG. 23

Features of firm support of the head of the talus, as seen in the standardized roentgenogram. This was a case of mild claw-foot.

light they throw upon the relationship of bony structure to deformity and function. It is a technique of research, by means of which we may secure otherwise unobtainable information regarding the skeletal structure of feet, the appearance and function of which can be assessed by clinical examination. In the problem of diagnosis, roentgenograms supplement, but do not replace, clinical examination. Hypermobile flat-foot with short tendo achillis can be recognized best by its distinctive clinical features,—short tendo achillis, hypermobility and instability of tarsal joints, and deformity which is present only when weight is borne upon the foot.

SUPPORT OF THE FOOT

Passive Support by Bones and Ligaments versus Active Support by Muscle Power

In this paper the conception is advanced that the function of the foot and its shape under the stress of weight-bearing depend chiefly upon the design of the tarsal bones and their position in relation to each other. Deficiencies in structure of the talus and calcaneus result in a weak, flat foot; conversely, the foot will be strong and well shaped if the tarsal bones are so shaped and so fitted into each other that they cannot shift when weight is imposed upon them. Since this conception is contrary to the widely accepted view that muscle power is the important factor in maintaining the shape and strength of the foot, some discussion of these opposing views is necessary.

Lack of accurate knowledge of the physiology of the foot, and particularly of the relationship of its structure to its function, makes it difficult to assess the relative importance of the passive factors (bones and ligaments) as compared with the active factors (muscles) which provide support to the foot. In most discussions on foot function, it is implied that the body structure of the foot follows a fixed pattern. In consequence, it is assumed that the support which is provided to the foot by its bony framework is the same in every foot, and that variations in the strength of the foot are dependent to a great degree upon the power of muscles.

The information derived from the Canadian Army Foot Survey and from previous studies leads us to the conclusion that, in the foot more than in any other part of the body, variations in the shape of the skeletal units and in their relationship to one another profoundly modify the stability, the shape, and the function of the foot. Such variations are common and occur through a wide range. It is incorrect to assume that there is uniformity of bony structure in all feet, or that the support provided by the architecture of the foot is virtually the same in every case. The tarsal bones, especially the talus and calcaneus, vary in their shape, in their position relative to one another, and in the manner in which they articulate with one another. These variations occur through such a wide range that it is impossible to define precisely what is normal. It is clear, however, that at one extreme of the range of variation the relationship of the tarsal bones to one another is unstable. Even with the aid of support from ligaments and muscles, they are ill-adapted to weight-bearing and can readily be distorted by superimposed stress. At the other extreme, the shape of the tarsal bones and their relationship to one another is such that they virtually interlock; and the more weight they bear, the more firmly they settle down into one another (Figs. 13 to 16-B).

One might compare the leg and foot to an obelisk (the tibia), based on a plinth consisting of two superimposed foundation stones (the talus and calcaneus). If the foundation stones are smoothly cut with all surfaces at right angles to each other, if they fit accurately and are precisely superimposed upon one another, and if they rest upon a level foundation, the weight of the shaft is carried without danger of collapse. Should the foundation stones be imperfect in their outline, tilted, or not accurately superimposed on one another, the weight of the column is off center and the structure is unstable (Fig. 24).

It is impossible, therefore, to discuss the problem of weak feet without taking into

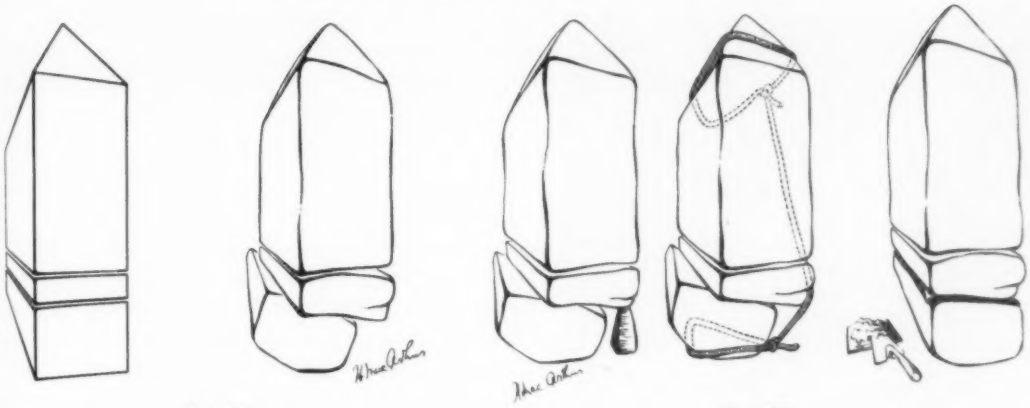

FIG. 24 FIG. 25

Fig. 24: Sketch to illustrate structures analogous to strong and weak feet. An obelisk of well-cut and well-fitted stones is stable and supports weight without difficulty. If the stones are irregular in shape, poorly fitted, and badly placed, or if they have slipped, the structure is unstable and shifts when weight is imposed upon it.

Fig. 25: Diagram illustrating the various principles of treatment for hypermobile flat-foot with short tendo achillis. (a) The weak skeleton may be supported by an external prop,—for example, a Whitman plate. (b) The muscles and their tendons may be utilized as slings to support the unstable skeleton. Increased muscle power by exercise increases the efficiency of this mechanism. (c) The unstable skeleton may be made stable by fusion, as are the stones by cementing them together.

consideration their bony framework. Moreover, it is useless to discuss structure in general terms; it must be related specifically to each particular flat foot. Feet are as individualized in their structure as are other parts of the body; but, while variations in structure make no difference in the function of noses, ears, or even hands, they are important with feet. Efficiency in weight-bearing and propulsion is profoundly influenced by their skeletal structure.

While the stability of the foot and the maintenance of its normal shape depend to a great extent upon its bony structure, this does not exclude contributions to its support from ligaments and muscles.

It is not easy to determine exactly the part which ligaments play in providing support to the foot, since direct study of their function is difficult. It seems reasonably certain, however, that some ligaments provide direct support to superimposed structures (such as the spring ligament supporting the head of the talus); while others, by limiting movement at the tarsal joints, prevent displacement into positions of instability (perhaps the interosseous talocalcaneal ligament).

The contribution of the muscles to the support of the foot is more easily ascertained, even though the mechanism of their functioning is complex to the point of confusion. It is possible for muscles to maintain the normal shape of the feet and to support the load imposed upon them, provided the feet are not rigid. The effort involved in doing this will vary with the adequacy of the support provided by the skeletal framework. This is well exemplified by the type of flat foot under discussion. Its deformity can be corrected by muscle power, although this involves an unusually great effort and calls into play muscles not commonly used. This muscle mechanism is only for occasional use, however. It involves too much effort to be long maintained. In few cases of hypermobile flat-foot with short tendo achillis is the deformity eliminated by the use of the muscles, even though they can be used for this purpose on occasion.

The support and stability which are provided the foot by its bony structure vary from foot to foot within wide limits. The task in load and balance which remains for the muscles varies inversely with that assumed by the bony framework. The strongest, most stable foot is that in which the tarsal bones interlock with one another in such a manner as to transmit the body weight directly to the ground. Such a foot requires its muscles only for fine

FIG. 26

A foot completely paralyzed from poliomyelitis for thirty-five years. It is not flat, even when weight is imposed upon it. Its arch is maintained by a stable tarsus.

adjustments of balance, and for accommodation to irregularities in the ground. The less stable the bony framework, the greater is the load thrown upon the muscles. The severe cases of hypermobile flat-foot with short tendo achillis represent the extreme of skeletal instability and the maximum of muscular effort.

That bony structure is of greater importance than muscle power in providing support to the foot is illustrated by the well-known observation that feet, completely paralyzed by poliomyelitis, often have little deformity. Even in the complete absence of any muscle power to control the position of the foot, flat-foot usually does not occur. In such cases, the maintenance of a normal contour of the foot and the freedom from symptoms of foot strain must necessarily be due solely to a stable relationship of the skeletal units of the tarsus (Fig. 26).

In summary we may state that support is provided to the normal foot both by passive factors (bones and ligaments) and by active factors (muscles), and that these factors are reciprocal. In the average or strong foot, most of the support is provided by the passive factors; little load is thrown upon the muscles. Much greater stability and strength for the foot can be obtained from the passive support derived from a well-designed skeleton than can ever be provided by muscles. The muscles, however, always play some part in maintaining balance and supporting the load. This function is least when the skeletal structure of the foot is such as to support the body weight without shifting. If the tarsal bones are less favorably placed for weight-bearing, in relation to each other, sufficient support may still be provided to the foot by increasing that which comes from muscle contraction. The less the structural support provided by the skeleton, the greater the contribution demanded from the muscles. Within a wide range of what might be called average feet, the complementary contributions from the skeleton and from muscles provide satisfactory stability and support. When the skeletal units are weakly disposed, however, the load thrown upon the muscles is unduly great, and they cannot sustain it continuously. The strongly disposed tarsal skeleton can sustain the whole body weight without difficulty, but the same is not true of muscles. They can function as important complements to skeletal support, but they cannot alone sustain the body weight for more than a brief period of time.

The *strong foot*, therefore, is one in which the tarsal bones are so shaped and so articulated with each other as to bear the weight of the body without appreciable movement between them. Its muscles are used to maintain balance, to adjust the foot to uneven ground, and, of course, to propel the body in walking or running. The *weak foot* is one in which the tarsal bones are so shaped and are so disposed in relation to each other as to be unstable and to shift in position when weight is imposed upon them. Only by increase in the support provided by the muscles can the normal shape of such a foot be maintained and the body weight supported. There is a limit to the contribution of this type which muscles can make to the support of the foot. They cannot function unremittingly, nor can they ever provide such powerful support as can the skeleton.

In hypermobile flat-foot with short tendo achillis, the skeletal support provided to the foot is subnormal, because of a deficiency in the support provided the talus by the calcaneus. In all its varying degrees from mild to severe, it demands greater effort from its muscles than does the more stably constructed foot. In mild or moderate grades of hypermobile flat-foot with short tendo achillis, the contribution of the muscles to the support of

the foot may be adequate for all average needs, but there is always a limit to the load which can be imposed. In severe cases, there is inability to meet even the moderate demands of a life of quiet activity. In less severe cases, a man may meet the demands of average activity, but will break down under the strenuous life of a soldier.

TREATMENT OF HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

Obviously no single form of treatment is suitable for all cases of hypermobile flat-foot with short tendo achillis. What is necessary to rescue the severe case from lifelong incapacity is needlessly radical for the mild case. The many factors which must be considered in planning treatment arrange themselves into three groups:

First is the great variation in the severity of the lesion. This is dependent upon the degree to which the tarsal skeleton fails to provide adequate support to the foot. There is every gradation from the normal, completely stable foot, capable of bearing unlimited weight without deformity or disability, to the foot so unsound structurally that it presents the extreme picture of severe hypermobile flat-foot with short tendo achillis. Within this range, widely different treatment is necessary. In the severe cases, permanent relief can be obtained only by operation; only the simplest management is needed in the mild cases.

Second, age modifies both the type of treatment and the lesion itself. The degree of disability caused by the hypermobile flat foot with short tendo achillis increases with advancing decades of life. In childhood, even a moderately severe degree of hypermobile flat-foot with short tendo achillis may cause no symptoms. By adolescence, it is certain to be giving trouble. In young adult life, it will be significantly disabling. At the age of forty and over, the disability may be increased by the growing burden of increasing body weight, by diminishing strength of muscles, and by the development of additional foot problems accessory to the main lesion (hallux valgus, osteo-arthritis, or localized points of pressure on the sole of the foot with callus formation). These changes in the degree of disability are not the result of increasing structural weakness, but of additional stresses which come with advancing years, and the diminished efficiency of the compensatory support provided by the muscles.

Independent of any changes in the degree of disability with advancing years is the important fact that what may be sound treatment in adult life may be bad treatment in childhood. This applies particularly to operative treatment, should it be necessary. The severe cases of hypermobile flat-foot with short tendo achillis can be greatly improved by appropriate surgical procedures, but it is unwise to perform these in childhood. These should be postponed until late adolescence or early adult life.

Third, the effort which is demanded of feet influences profoundly the degree of disability. A life of quiet activity with little physical effort, no strenuous sports, and the opportunity to perform the necessary tasks in the time and manner best suited will often reduce disability to the point where it is insignificant. Conversely, strenuous occupations or sports, especially those which demand long standing or much walking, will result in great incapacity. Such occupations as nursing, laboring, and soldiering are impractical or impossible, if the degree of hypermobile flat-foot with short tendo achillis is more than moderate.

The various measures which may be used for the treatment of hypermobile flat-foot with short tendo achillis fall into three groups (Fig. 25).

1. *Measures to Provide Extraneous Support to the Foot:* This group includes the great variety of accessories and procedures which attempt to support the foot from without (such as arch supports, modifications to boots, and special boots). They are of undoubted value. By supporting the foot, they reduce the load which otherwise would have to be carried by the muscles. There are decided limitations to their usefulness. They do not alter the underlying structural fault, and consequently their effect is only palliative. Also, their

efficacy is low. Even so they have a place in the treatment of this ailment. Those of most value are (1) arch supports of the Whitman type, made from plaster models of the feet; and (2) boot modifications. Of these, the most important is raising the heel. A thick inside lift from heel to toe is also of some value.

2. *Exercises to Develop Muscle Power:* Properly planned exercises, persistently and conscientiously carried out by the patient, can increase the power of the muscles which motivate the foot. By their use, the support to the foot which can be provided by the muscles is materially increased. Foot exercises, properly used, are important in the management of hypermobile flat-foot with short tendo achillis, but it must be admitted that frequently the result obtained from a program of exercises is imperfect. There is a limit to the improvement which will follow increased muscle power, no matter how great that increase be. Too often, also, the best result is not obtained, because of imperfect planning of the exercises or failure of the patient to perform his part conscientiously and persistently. The muscle training must be directed to specific muscles (invertors and plantar flexors), and must be maintained continuously for a long period of time. It is possible that improvement in the results obtained by muscle exercise will shortly be achieved by the application of new principles of muscle development, particularly the principle of heavy-resistance exercises, advocated by DeLorme.

3. *Operative Measures in the Treatment of Hypermobile Flat-Foot with Short Tendo Achillis:* For the severe cases of hypermobile flat-foot with short tendo achillis, no form of external support and no program of muscle retraining offers more than palliative relief of symptoms, and even this is imperfect. The patients face a life of semi-invalidism, because of the greatly diminished capacity of their feet to bear weight and to propel their bodies in walking. Since the basis of the lesion is inadequate support of the head of the talus by the calcaneus, so that, under stress, the head of the talus slides medially off the calcaneus, improvement can be obtained by fixation of the talus in suitable relationship to the calcaneus.

This can be accomplished by various operative procedures, but only those which fuse the tarsal bones are of real merit. Hoke's subtalar and mid-tarsal fusion,* presented in 1921, is effective. The loss of movement at the subtalar and mid-tarsal joints is more than compensated by the great increase in stability and strength of the foot. This operation, however, is of considerable magnitude and carries with it a risk of avascular necrosis of the body of the talus, as pointed out by Marek and Schein.

Gallie's subtalar fusion through a posterior approach gives satisfactory fusion of the subtalar joint, but leaves the mid-tarsal joint still unstable and hypermobile. This may mar the perfection of the result.

The authors' present procedure has the merit of simplicity. Through a medial approach, the talonavicular joint and the joint between the sustentaculum tali and the neck of the talus are fused by removal of their articular cartilage and the implantation of cancellous bone grafts. To date the results seem satisfactory, but too short a time has elapsed for adequate assessment. This will be reported in a later paper.

Lengthening of the tendo achillis alone has been advocated and practised for the treatment of hypermobile flat-foot with short tendo achillis. It results in considerable improvement in the foot, since the invertors of the foot can act to greater advantage when freed of the stress imposed by the short tendo achillis. It does not modify the essential structural weakness and, since it materially weakens the power of the triceps surae, it is not a satisfactory procedure.

Operative treatment of hypermobile flat-foot with short tendo achillis, which involves tarsal fusion, should not be undertaken in childhood. The plasticity of the bone at that age will invite recurrence of the deformity, if stress is placed upon the foot, even after successful fusion. Late adolescence or early adult life is best for tarsal arthrodesis.

* This is not Hoke's operation for flat-foot, but that for stabilizing paralytic feet.

We estimate that 10 per cent. of the cases of hypermobile flat-foot with short tendo achillis are suitable for treatment by operation.

General Plan of Treatment

With so many variables in the problem, it is well to outline a general plan of treatment of this lesion. It can best be considered in age periods, as summarized below:

Childhood: Support of the Whitman type; modifications to boots, raising of the heel to reduce tension of tendo achillis, inside lift from toe to heel; muscle exercises to develop power of foot invertors. No operation should be performed, even in severe cases.

Adolescence: Continue Whitman supports and lift to heel. Every effort should be made to develop muscle power. In severe cases a regimen of reduced physical activity is needed. In late adolescence, operation may be performed for the worst cases if the symptoms are justifiably severe.

Young Adult Life: Continue Whitman plates if necessary. Continue use of raised heel if necessary. Operate upon patients with the most severe symptoms. Seek employment within capacity.

Maturity: By this time, some degree of stable adjustment has usually been reached. By trial and error, a mode of living has been achieved which demands the minimum of the feet. Whitman plates may be continued to advantage, and are more useful than special boots.

SUMMARY

The clinical features which distinguish hypermobile flat-foot with short tendo achillis are:

1. A prolonged history of some degree of foot disability extending back into childhood, the degree of disability tending to increase. There is often an hereditary tendency.
2. Flat-foot deformity which is mobile. It disappears when the feet are freed of weight-bearing, and appears when the patient stands. It can be corrected by muscular effort.
3. A short tendo achillis, which limits dorsiflexion at the ankle joint.
4. Hypermobility of the mid-tarsal and subtalar joints.
5. A deformity which is often severe and of characteristic appearance.

Evidence from anatomical and roentgenographic studies shows that hypermobile flat-foot with short tendo achillis results from unstable architecture of the tarsal bones, especially their configuration and position in relation to each other. This results in imperfect support of the head of the talus by the calcaneus.

CONCLUSIONS

The common severe flat-foot deformity of childhood and young adult life is due to abnormalities of the tarsal bones, which result in instability of the tarsus, manifested when weight is superimposed upon the foot. The chief lesion is inadequate support of the head of the talus by the calcaneus. To a degree, the diminished stability and support of the tarsus can be compensated for by increased action of muscles. They cannot fully compensate for the more severe grades, so that flat-foot of a severe degree results. The clinical features of the lesion justify the use of the descriptive title "hypermobile flat-foot with short tendo achillis", to distinguish it from other forms of flat-foot and to indicate the chief features of its clinical picture. Treatment is determined by the age of the patient and by the severity of the lesion. Severe cases are benefited by operation, which should be postponed until late adolescence or young adult life. Mild cases and youthful patients are best treated by foot supports and muscle exercises.

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DISCUSSION

Dr. Frank D. Dickson, Kansas City, Missouri: I applaud Colonel Harris and Major Beath for bringing before the Association this important subject of hypermobile flat-foot with short tendo achillis. We of the orthopaedic group have become so preoccupied with the more dramatic aspects of our specialty that we are prone to push aside so prosaic a condition as flat-foot. Royal Whitman said many years ago: "If one has a cut on the finger or a felon, he goes to the hospital and has surgical treatment. If he has a painful foot, he is the subject of ridicule and is sent to the shoe salesman for relief."

Symptom-producing flat-foot is an important part of orthopaedic practice, since it is a widespread medical condition; it is, as well, an economic problem of considerable magnitude. It is, therefore, worthy of our careful attention, since the main hope for relief rests with the orthopaedic surgeon. Our experience coincides with that recorded in this paper,—namely, that hypermobile flat-foot with short tendo achillis in some degree is the most common single form of foot imbalance, that it is the most likely to produce symptoms, and that it manifests itself in childhood and young adult life. This latter fact is important and should be constantly held in mind in appraising foot posture in children, for it is at this age that corrective measures should be initiated.

It has long been appreciated that a short heel tendon restricts normal dorsal flexion of the ankle joint. In consequence, as weight falls upon the foot, in order that the heel may come down to the ground, the calcaneus assumes a valgus position, the head of the talus rotates downward and inward, and the fore part of the foot swings upward and out. These complex but correlated movements result in a pronated foot, with concentration of weight stresses on the depressed medial border. In the past, it has been taken for granted that such a faulty foot attitude was due to giving way of the whole foot structure, the result of stretching of ligaments and muscle relaxation, following continued excessive stress, and that it was concentrated on the medial side of the foot by reason of the short heel cord. The investigations by Dr. Harris and Dr. Beath offer very persuasive evidence that anatomical abnormalities in the os calcis, and to some extent in the astragalus, resulting in structural faults in the subtalar joint, are the etiological factors in the production not only of the pronation of the foot, but of the short tendo achillis as well. This is indeed a new point of view, but one which has sound support. In an extensive series of 3,619 cases, 76 per cent. of the more severe cases of hypermobile flat-foot with short tendo achillis showed weak support for the head of the astragalus, due to structural abnormalities of the os calcis; while only 9.1 per cent. showed such structural weakness in normal feet. It would seem that the anatomical abnormalities in the os calcis and astragalus, which have been so clearly demonstrated, are probably throwbacks to the arboreal foot in which the astragalus, os calcis, and the subtalar joint have characteristics resembling those described.

It should be recognized, however, that probably not all cases of hypermobile flat-foot with short tendo achillis are due to anatomical faults of the os calcis or the astragalus. In some, the short heel tendon alone is the etiological factor, — at least, I have seen a very considerable number of such patients respond to simple lengthening of the heel cord.

Dr. Edwin W. Ryerson, Chicago, Illinois: From this very interesting discussion, one somehow gets the picture that a portion of the astragalus swings inward and becomes displaced. That, I think, is a misconception. The talus is held very well by the notch into which it fits. Its motions are mostly flexion and extension, and not lateral deviation. My picture of this kind of flat-foot is that all the rest of the foot, including the calcaneus, navicular, cuboid, and the other bones, swings around the head of the talus and that the talus remains pretty well fixed.

I do not like to lengthen the tendo achillis operatively, because it takes some time for it to unite. It displaces the gastrocnemius and soleus up toward the knee, and the result is that the calf is not as beautiful as it should be. One achieves the same result by inverting the foot and fixing it in a plaster cast for three or

four weeks, and perhaps renewing the cast for another three or four weeks to allow the muscle to stretch. The tendo achillis is not short; the muscle bellies are short, but the tendo achillis is long enough.

DR. JOHN R. MOORE, PHILADELPHIA, PENNSYLVANIA: This paper is very interesting because it revives the probable structural causes contributory to hypermobile flat-foot. Personally, I feel that the authors are overstressing the structural defects and minimizing the importance of the muscles and of posture. I do not feel that a short heel cord can be diagnosed on the basis of the test shown in the moving picture. If this test is the basis for the evidence concerning the short heel cord in this particular type of foot, I question the value of the material. The heel cord must be tested with the knee fully extended and also with the foot at a right angle, in order to determine whether the heel cord and its muscle are at fault, or whether it is the capsule of the ankle joint, or some other possible cause. If the knee is hyperextended during the testing, even a normal heel cord may give the impression of being short, due to the fact that the gastrocnemius originates on the femoral condyles.

One of the authors stated that Dr. Hoke made a mistake in his analysis of flat-foot, by ascribing the principal cause of flat-foot to muscle imbalance. Dr. Hoke did not ascribe the weak foot or the hypermobile foot to muscle imbalance alone, but stressed equally the structural defects and muscle imbalance. He recommended lengthening of the heel cord when it is contracted; and he also recommended a scaphocuneiform arthrodesis for two purposes,—first, to re-establish the normal astragaloscaphoid fulcrum, and, second, to re-establish a sound lever arm for those muscles normally employed in maintaining balance of the arch and foot. I feel that the authors have overstressed the structural defects as possible causes of hypermobile flat-foot.

DR. JOHN L. MCDONALD, TORONTO, ONTARIO, CANADA: I want to compliment Dr. Harris and Major Beath for their presentation, and also to express my appreciation for the way in which they explained the underlying cause of flat feet in children and young adults. Most of us are thoroughly familiar with the clinical picture presented by these patients. Those of us who are associated with children's hospitals, as I happen to be, are also familiar with the large numbers of patients who turn up for relief in the out-patient clinic and in private practice, particularly if one gives them the attention they deserve.

As I understand it, the arch of the foot is maintained by three main factors: first, the shape of the bones and their relation to each other; second, the supporting ligaments; and, third, the supporting muscles. I believe Dr. Harris and Major Beath have shown very clearly that, in a high percentage of children and young adults with flat feet, there is disturbance in the shape of the bones and in their relationship to each other. The relationship of the head of the astragalus to the os calcis is very clearly disturbed in these severe cases.

In searching for a means of overcoming this disability, we have found in a great many cases that conservative measures fail to give relief. We have tried various procedures, including foot exercises, corrective shoes, and the wearing of Whitman plates; but in most instances patients continue to have flat feet which, as time goes on, become a source of serious disability.

Some twenty years ago we were much impressed by the contribution of the late Dr. Michael Hoke to this subject, and were encouraged by the results he obtained by operative treatment. He was of the opinion that the cause of the deformity was a rotation outward of the fore part of the foot at the scaphocuneiform joint, associated with a short tendo achillis. He recommended fusion of the scaphocuneiform joint after correction of the rotation of the fore part of the foot, followed later by a lengthening of the tendo achillis.

We carried out the Hoke procedure on several patients, and were somewhat disappointed in the results obtained. Later, we tried the procedure described by Dr. Kidner of Detroit—namely, a transplantation of the posterior tibial tendon to a new insertion—but here again we felt that, although the feet were improved, the results were not so satisfactory as one might desire. This led us, about sixteen years ago, to a new operative procedure,—namely, arthrodesis of the astragaloscaphoid joint, associated with transplantation of the insertion of the posterior tibial tendon to a new position. We have followed this method since, with very gratifying results.

One other point which I believe to be of considerable importance is the most suitable age at which to submit the patient to operation. Dr. Harris stated that operative interference should be deferred until adolescence or young adult life. Personally, I do not think it is necessary to wait so long, and I believe that these children can be operated upon at ten to twelve years of age with very satisfactory results.

Up to the present, we have reserved the operation for those patients with extremely flat feet. I think we have been too conservative and, as time goes on, we shall be inclined to operate upon more patients with moderate disability.

We have recently made a study of a number of patients, operated upon ten or more years ago, who have now reached adult life. We are greatly impressed with the normal appearance of the feet and with the finding that the patients are able to carry on an active and useful life, without foot disability.

DR. J. WARREN WHITE, GREENVILLE, SOUTH CAROLINA: I have been extremely interested in this subject. I think we all know about the book which Professor Dwight wrote many years ago on variations of the small

bones of the hands and feet, in which he described astragalar variations. I would like to ask Dr. Harris his opinion about the shortening procedure of the long neck of the astragalus, which I described a few years ago. I am still doing it and it seems to be working out quite satisfactorily.

A few words about this elongated neck would appear to be in order, as Dr. Harris has mentioned anatomical variations of this bone. Others than myself have tried to lay the blame for one type of flat-foot upon the shape of this bone and the disturbed function of the tendon so closely associated with its head. In shortening the astragalar neck, we are allowing the anterior tibial tendon to function more satisfactorily and, as we saw in the moving pictures, the scaphoid slides back and forth over that projecting astragalar neck. It has a hard time rounding the head, so why should we not shorten the astragalar neck and at the same time change the insertion of the anterior tibial tendon? It does produce a still greater varus of the fore part of the foot, and the insertion of the anterior tibial tendon is displaced farther medially. This is a distinct advantage in giving support for the arch. If, at the same time you shorten the astragalar neck, you go in from the outside and make an osteotomy posterior to the calcaneocuboid joint, you further increase the lateral border and you have a more normally shaped foot. That helps in the correction of congenital valgus of the fore part of the foot. I have found it of considerable value.

I would like to hear what Dr. Harris has to say.

Dr. Compton Riely, Baltimore, Maryland: It has been very interesting to hear these papers, which seem to me very important, because it looks as if we know less about flat-foot than we do about many other things. I shall never forget a visit I made to Dr. Whitman's clinic many years ago. I told him I had difficulty in the treatment of flat-foot. The first question he asked was: "How do you take the impression?" I said I put the foot down in the plaster, obtained a mold, made a cast, and then had a support made over it. He said: "I am going to show you how wrong that is. I have a flat-foot coming in right now." He sat the patient on a seat, flexed and rotated the knee outward, and put the foot around in position to draw the astragalus into line. You remember that Gray and other anatomists state that the normal direction of the astragalus is upward, forward, and out. If the outer extremity of the astragalus is turned up, it throws everything else out of line.

After I went home and took impressions that way, I found that I had entirely different results. He had done away with the valgus of the foot.

We have not only to consider the feet in flat-foot, but also the hip joint, the knee joint, and the toes. In many of the cases shown here this morning, the toes were bound down so that their ends were pressed backward, causing the foot to be abducted; also, in an effort to maintain balance, the knee would be hyperextended.

We all seem to forget that the ends of all long bones have an eccentric action and, if those bones get out of alignment—if you have knock-knee or bowlegs—you have to do something to the bones.

One other great cause of flat-foot, in my opinion, is the wearing of short shoes. In recent years, I have noticed that a great many babies coming into the clinic have short shoes. They do not look short, but the toes of the shoes have been so sloped that it makes the shoe much shorter than the child could wear if the toes had been vertically higher in front. Another very important thing is to have the arch of the shoes at the proper point with the proper pitch, and not too high.

Following the method of Whitman, I have the shoes made and that is all. I do not direct the patients to take any special exercises, only teach them how to walk properly, but I see that the arches are put into the shoes in the proper place. (All manufacturers whose shoes I have looked at, whether for men or for women, have the arches placed too far forward.) If you will take that into consideration, you should have to do few operations.

As for lengthening the tendo achillis, I have done that, but to me the result was not worth while.

Dr. Halford Hallock, New York, N. Y.: This paper has been most important. There are many causes for flat feet and many pathological factors involved. I think the discussions have brought out the fact that we do not know too much about these various causes. The more we find out about them, the sooner we will be in a position to apply intelligent treatment. I would like to emphasize this point in the paper,—that this is another effort toward clarifying the fundamental factors in this entity. A great deal of work has been done by many men on the fundamentals, notably, Hibbs, Hoke, and Dudley Morton, who really began the study of the anatomical variations of the foot and its evolution. Others, however, have been concerned chiefly with the front part of the foot, with relation to the shortness of the anterior segment. Dr. Harris is concerned with the lower portion of the foot. I think the whole foot has to be considered. I am glad to see these factors brought to our consideration, and I hope that other groups will take them up.

I would like to mention one thing for Colonel Harris's benefit, that, in the discussion of abnormalities, nothing was said about the relation of the subtalar portion. Perhaps you would like to include that in a consideration of these anatomical factors.

Colonel Robert I. Harris (closing): It is gratifying and stimulating that our paper upon this ordinary subject should have brought forth so much and such informative discussion. I shall not try to answer all the

(*Continued on page 150*)

STRUCTURAL PATTERNS OF CALLUS IN FRACTURES OF THE LONG BONES

I. With Reference to Healing after Internal Fixation

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A broken bone is healed when a complex, but highly specific, histological and biochemical reaction has restored the continuity of its network of mineral-impregnated trabeculae. The newly formed ossific tissue which effects this reconstruction forms a mass, developing at first about the shaft in the vicinity of the fracture, and later invading the fibrous soft callus which had previously bridged the fracture space and united the fragment ends. This ossific mass has been studied intensively from the histological and biochemical viewpoint, but its morphological characteristics have been all but neglected since the classical work of James Paget, early in the nineteenth century. Furthermore, the use of tracings of roentgenograms, taken at repeated intervals, presents a dynamic rather than a static approach to the study of the structural development of the ossific mass, which was not available in Paget's time. Such tracings form a basis for the present study. During this investigation, it became apparent that the ossific mass develops along predictable morphological lines, and that its forms remain uninfluenced by certain factors, but vary in a specific direction with others. Recognizable deviations from these norms were often the earliest indications of extraneous influences, or of probable, if not irreversible, non-union.

The form or pattern of the mass often appears grossly irregular and apparently without design, when examined directly through a wound or surgical incision. However, when its outline is studied by means of tracings of its silhouette made from a good roentgenogram, a remarkably clear picture of a purposeful pattern can be discerned. A series of such tracings was made from a large unselected collection of fractures of the shafts of long bones, treated by standard non-operative methods. From these tracings there evolved a set of regularly repeated patterns, which followed easily recognizable rules. These patterns, after allowance for variations in size and degree of density, and minor variations in contour due to the shadows of the ridges and nodules formed in their development, could be correlated with the type of fracture and the relative position of the fragments during the greater part of the early weeks of immobilization. In these tracings no attempt is made to show the internal architecture of the ossific mass, but rather its structural outline. The variations in density, which occur within the developing mass and are more or less distinctly visible on the roentgenograms, are expressions of differences in the time factor of ossification in different areas. Eventually, a fairly homogeneous density appears in cases with normal healing.

BASIC PATTERNS

Type Pattern

By the end of the sixth week, the periosteal ossific mass in a normally healing fracture of a long bone is a firm structure, reaching from a variable distance on each side of the fracture space and crossing it. Its thickness in reference to the diameter of the shaft varies in circumference and also in its length. It is least at the extreme distances from the fracture site, but not necessarily of greatest depth at that site. Often the periosteal mass is deeper a centimeter or two away from the fracture.

Simplest Pattern

The simplest pattern formed by the ossific mass is that which occurs in fractures near the ends of the shafts of long bones,—that is, through predominantly cancellous tissue

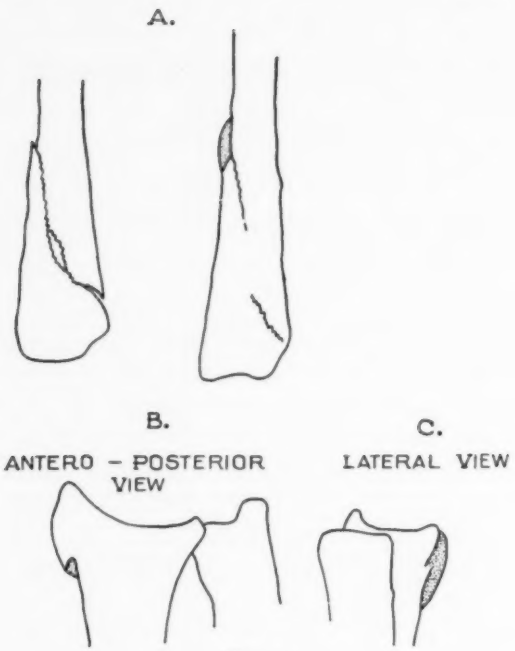

FIG. 1

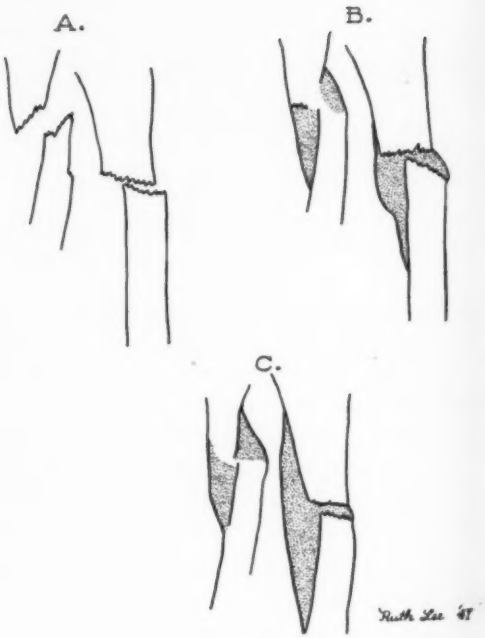

FIG. 2

within thin cortex, in which there is little or no displacement. Figure 1 shows characteristic tracings of two such types: One is a fracture in the lower end of the fibula; the other is the common fracture of the distal end of the radius. Little evidence of an ossific mass appears outside the fracture space, either on the tracing or under direct vision at the operating table. Most of the ossific mass in these cases is internal,—that is, it derives from the endosteum and spongiosa. Since there has been no significant displacement of the axis of the shaft, there is no significant shift in the lines of force to which the fractured bone is subject. The apposition of the fracture surfaces, even though cemented only by the fibrocartilage of soft callus, is such that little external support is required. This slight addition is supplied by the external ossific mass, formed as struts, however small, along lines required by the functional compression force in the long axis of the bone. These struts are constructed relatively rapidly, long before the "fracture line" disappears from the roentgenogram or from histological sections, and are resorbed to a greater or lesser degree, depending upon their functional usefulness, after the fibrocartilage has been replaced by the internal ossific mass. *The volume of the external ossific mass is in direct proportion to the degree of displacement.* In the simplest pattern this is, therefore, minimal.

Patterns Formed with Displacement of Fragments

The patterns more commonly seen are those exhibited in fractures of the shaft between the metaphyseal expansions. Several variants are shown in Figures 2, 3, and 4. Figure 2 is a tracing from the roentgenograms of a fracture of the proximal portion of the shafts of the radius and ulna. The radius was displaced to a degree which left no contact of the fragments, and this position could not be improved. Hence, until such time as the soft callus could be replaced by the ossific mass, a mechanism was required which would temporarily transmit the stresses to which the fracture was being subjected. The most economical means of constructing a temporary brace was to drop an ossific strut from the lateral periphery of the upper fragment to the lateral surface of the lower fragment, reaching as far distal as was necessary to form a relatively straight line of transmission of compression force (Fig. 2,*B*). This is the characteristic pattern of all fractures of the long bones in which there is complete displacement of the fragments of the shaft. In the neigh-

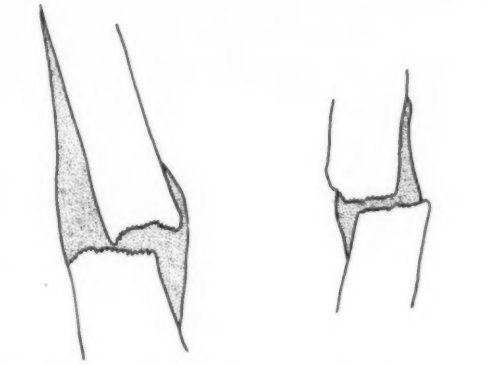

FIG. 3

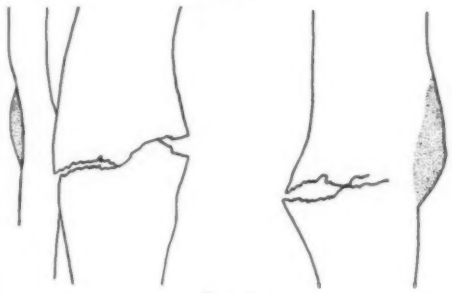

FIG. 5

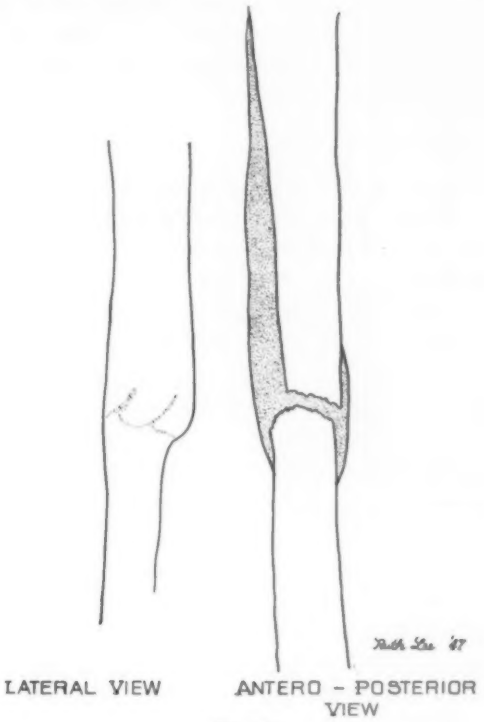

FIG. 4

boring ulna, displacement was not so great, but was about 50 per cent., with moderate angulation. In this situation, the line of force transmission in the lateral half of the cylinder crossed the fracture line, starting from a considerable distance along the distal fragment. As will be seen in Figure 2,*B*, during the development of the strut, the line was dropped from the proximal overhanging ledge to the distal portion of the shaft, which is again the most economical position from a mechanical viewpoint. In this case, as was to be anticipated, the fracture lines were still visible long after effective healing had been manifested by unrestricted function of the limb. The significance of this will be discussed later, but the fact is important in the consideration of the structural pattern.

Figure 3 shows a variation of the same pattern in a femur with partial lateral displacement and some angulation. Here again, in the anteroposterior view, is seen an ossific mass, large enough to be a prolongation of the lateral surface of the lower fragment in an almost straight line. On the medial surface appears a smaller strut to brace the overlapping medial periphery of the end of the upper fragment. The lateral view shows some displacement, but no significant angulation. It is obvious, when viewed mechanically, that at this point very simple and small struts are required; and such were constructed. In Figure 4 is traced the common fracture at the juncture of the middle and lower thirds of the tibia in a case where healing was normal in average time. In this case, a narrow band of the ossific mass can be seen in the lateral view. This narrow and unilaterally prolonged ossific mass is another variant of the patterns seen in Figures 2 and 3, and is characteristic of many transverse fractures of the tibia at this level with little displacement. In poor roentgenograms, or when the films are examined too casually, this type of case is often referred to as showing little callus. This stems from the common misinterpretation of the function of the external ossific mass as a welding material. Actually, when this pattern is examined from the points of view presented here—that is, the mechanical requirements for transmission of compression along the normal lines of force of the tibia—it will become apparent that no more callus is necessary.

These typical patterns were repeated regularly in all roentgenograms examined of cases in which healing was known to have been normal, and varied only enough to fulfill mechanical demands.

Discussion

It may be said, therefore, that the pattern of the external mass of any fractured bone represents the most economical structure which will serve as a rigid line of transmission for the stresses and strains normal to that bone in its long axis, until such time as osseous continuity through the fracture line has been restored. The mass appears first as a partially circumferential strut involving the periosteum, and remains in this position until internal healing is complete. The quantitative distribution of the mass about the shaft—that is, the external portion of the mass—will be conditioned solely by the mechanical requirements of the displacement of the fragments. These patterns are characteristic and vary in a normal case only with the position of the fragments. The external portion of the mass does not ordinarily exhibit a "welding" process. It is not structurally an essential part of the union, which takes place far more slowly within the fracture space, except in so far as its tissues later invade this space and contribute osteogenic elements to it. Furthermore, the external mass is to a greater or lesser degree absorbed after osseous continuity of the shaft has been re-established. While its form superficially may appear to conform to Wolff's law, it is fundamentally not in accordance with it. Wolff's law refers to a remodeling of the architecture of the healed bone in response to function. The pattern of the external ossific mass is an external strut or brace which temporarily holds two or more fragments in position, and transmits stresses outside the direct line of the axis. Wolff's law may operate later in the healed fracture, to restore direct alignment of the trabeculae of a deviated shaft. If part of the external ossific mass is required for this purpose during the remodeling period, that part may be retained, as the residue of the external mass is absorbed.

The patterns of the ossific mass appear to result from a reaction conditioned by physical factors of stress and strain, a fact recognized long ago in Paget's concept of "design". In an uncomplicated case, very little of this osteogenic material is wasted. The ossific mass, when completed, does not extend externally beyond the lines which can, within a very small margin of error, be anticipated. The ossific mass does not "enlarge" or "grow" from a single original center of deposition or from symmetrical centers. It may appear first as a narrow line along the shaft, some distance from the fracture line; or it may, as in Figure 2, appear first as a small node near the line. As the mass develops, separate centers rise asymmetrically, simultaneously or in sequence, and finally merge. However, no such center, in a case with uncomplicated healing, appears at a false point,—that is, it never appears more widely dispersed or at a greater distance from the fracture than will be necessary to form the mechanically required strut. The formation of the external portion of the ossific mass may be compared in certain respects to the temporary structures used in construction work to brace bridges or roofs while the original beams are being replaced or strengthened. While held by these ossific struts, physiological resorption and replacement of the bone ends of the fragments can proceed as part of the process of reparative osteogenesis, without collapse of the fracture space.

FACTORS GOVERNING THE EXTERNAL CONFORMATION OF THE PATTERN

Factors Inherent in the Trauma

1. *Influence of Periosteum:* An observation first brought to general notice by Paget is particularly pertinent to this discussion. Describing human fractures of long bones, he stated that periosteum is rarely much damaged, seldom stripped from the fracture line, and often remains remarkably adherent to the bone, "even in extensive fractures". The author does not recall seeing this noted elsewhere, and, in fact, has heard the contrary view stated many times. It has been taught repeatedly, on the one hand, that excess callus forms under

FIG. 6

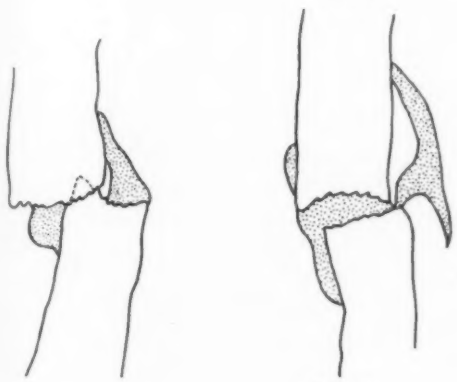

FIG. 7

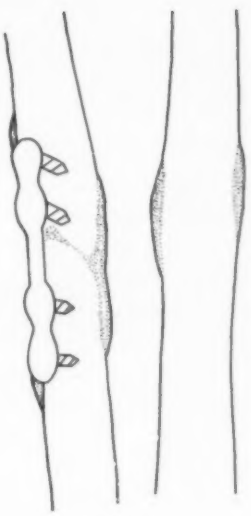

FIG. 8

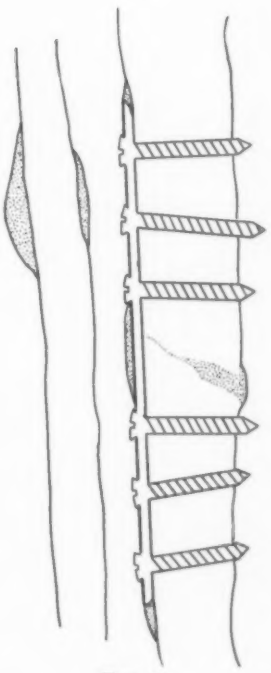

FIG. 9

the surface of stripped periosteum, and, on the other hand, that stripping of the membrane from the surface of the bone prevents callus formation. Neither of these two statements can be supported by direct observation. Paget's remarks proved surprisingly true in the many cases of severe open fractures seen abroad during the years of World War II. As he noted, there was far more often a tear at the fracture site, with periosteum remaining adherent to the cortex even of the comminuted fragments. Lacerated periosteum along the adjacent shaft was common enough; periosteal stripping of a centimeter or more was rare. Regardless of the appearance of the periosteum, the structure of the external mass developed in uncomplicated cases as the position of the fragments dictated. Even in certain cases of open fracture with large wounds in which, for various reasons, excessive callus formed subsequently, no significant detachment of the periosteum had been noted at the time of

the primary surgery. In cases of transverse, uncomminuted fractures of the femur, callus often reached fifteen centimeters (six inches) or more above the fracture site in the demonstrated presence of periosteum which was intact beyond the fracture line. In fact, the pattern of the ossific mass cannot be related to the degree of stripping of the periosteum or to the extent of its laceration.

2. *Fracture Hematoma:* A second factor which at times has been credited with influencing the extent of callus formation is the fracture hematoma. While the hematoma within the fracture space may or may not be an integral part of the soft callus, its importance to the formation of the ossific tissue of bone healing has been at times obviously overestimated. The development of a normal, or even extensive, external mass, in cases from which the blood had been immediately drained from the fracture area through large debrided shell-fragment wounds, precluded the possibility of any important relationship between hematoma and bone formation. It has been said that in such cases a secondary hematoma, derived from the intra-osseous circulation, replaces that of the original trauma. This is sometimes true within the fracture space. However, during the early part of the War, before delayed primary suture of wounds had been introduced, certain open wounds required repeated dressing because of resistant infection. Secondary hematomata did not collect within these wounds to any extent comparable to the excessive external callus often found in patients suffering a low-grade traumatic osteomyelitis. Furthermore, the earliest development of the external ossific mass often appears in the periosteum, several centimeters away from the fracture space, at levels which are demonstrably not within the sphere of a small hematoma. In brief, the concept of Stirling that callus in general is formed within a "shut-off chemical factory" is simply untenable. Certainly it cannot be demonstrated that the extent of hematoma bears any relation to the quantity of structural form of the ossific mass, and considerable observational evidence at the operating table indicates that it has no influence whatsoever on its development.

EFFECT OF TREATMENT ON PATTERN OF THE OSSIFIC MASS

Non-Operative Treatment

In all of the cases reviewed for this study, an attempt was made to define a possible relationship between the method of treatment and the pattern of the resulting ossific mass. (The time factor or relative efficiency of the method is not of concern in this study, which relates solely to the form of the mass in normally healing bone.) Closed methods of treatment of fractures of the shafts of long bones fall into two primary categories, traction or immobilization, the latter usually by plaster.* Each of these primary methods is subject to variations which attempt to solve local anatomical problems, but do not significantly modify the mechanical principles involved. One special group, fractures of the humerus, treated by the technique of the hanging cast, may be considered a combination of traction and immobilization. The same may be said for a few examples of another technique used in combined fractures of the tibia and fibula,—the double-pin plaster technique.

The success of immobilization or reduction and the efficiency with which the corrected position was maintained varied considerably with the type and location of the fracture, and with the method used; but the pattern of the ossific mass in each case known to have had normal healing reflected the position of the fragments during the period of formation of the mass, and bore no determinable relationship to any other factor.

These observations apply to fractures proceeding to normal healing. Structural evidence of impending non-union may appear at any time during the development of the ossific mass. The mass may appear in minimal or inadequate quantity (Fig. 5); it may develop either above or below the fracture site alone (Fig. 6); or it may appear unequally on both fragments and fail to cross the fracture line. Its variations are many. It may

* Patients treated during the healing stage by traction and later maintained in plaster were obviously considered traction cases.

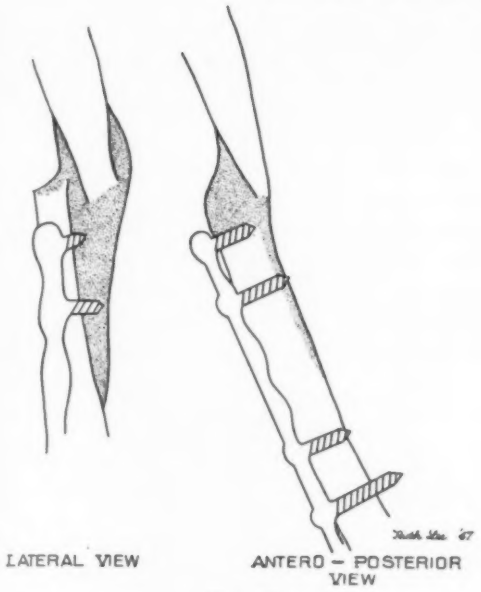

FIG. 10

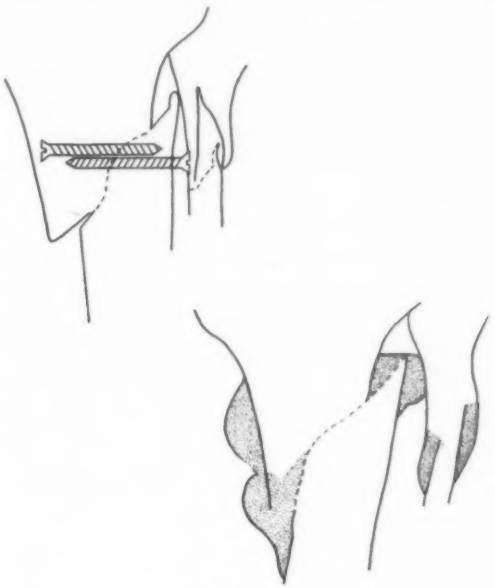

FIG. 11

develop apparently normally and, for some reason still unknown, be found involuting after a period of arrest (Fig. 7). On the other hand, low-grade infection following open fracture often acts as though it were a stimulus to excessive osteogenesis; but the mass in these cases does not develop normal patterns, and its quantity is never a guarantee that continuity will be restored between fragments.

Effect of Internal Fixation

A common source of uncertainty in gauging the results of fractures of the long bones, treated by internal fixation, is the difficulty in determining the time of effective bone healing. Experience has repeatedly demonstrated that, following internal fixation, effective stability in the healing bone may be obtained long before roentgenograms give evidence of those criteria of union which are ordinarily sought for in cases treated by other methods. The patterns of the mass are not those described in the preceding sections. Failure to appreciate this fact, or timidity in trusting its implications, has led too often to unnecessarily prolonged immobilization, and has thereby delayed the beneficial effects which earlier activity might have afforded.

It is a matter of common knowledge that the more accurately the fragments of a fractured shaft of a long bone are aligned, and the more efficiently they can be immobilized in good position, in the absence of extrinsic irritant factors such as infection, the less will be the quantity of the external ossific mass. This was demonstrated in the preceding sections, and may be related to the description of the simplest pattern. These two objectives are most precisely accomplished when fracture surfaces can be brought into hairline apposition at the operating table, and can be fixed rigidly by a plate or screw whose firmness will be maintained for six weeks or more. The rigid metal then takes over the temporary bracing function of the external mass to a greater or less extent, depending upon the mechanical soundness of its position relative to the fracture line and the efficiency of its application. Therefore, the ossific tissue which forms the external callus, visible on the roentgenogram, develops to a minimal degree in fractures properly treated by internal fixation, because greater quantity is not functionally demanded. Figures 8 and 9 show the characteristic appearance of the external ossific mass produced in well-fixed fractures of (1) the radius and ulna and (2) the tibia. Figures 10, 11, and 12 are tracings from cases which demonstrate that a plentiful supply of external ossific tissue will appear about the

fracture site, whenever its presence is functionally required because of poor or inadequate fixation. Therefore, the mere presence of rigid fixation does not in itself prevent or depress the formation of the mass. The apparatus must be placed efficiently if it is to take over the function of the external mass and make its appearance unnecessary.

Besides the frequent lack of an anticipated quantity of visible callus in these cases, a second factor contributes to the difficulty of estimating healing time. That is the interpretation of the significance of persisting translucent lines or areas along or adjacent to the original fracture line, visible on the roentgenogram. They are often attributed to any one of three possible defects,—distraction of the fragments, failure of callus formation, or the inability of the fragment ends to become impacted, following the bone necrosis of the fracture surface which is normal to this area in a healing fracture. Often the plate is blamed

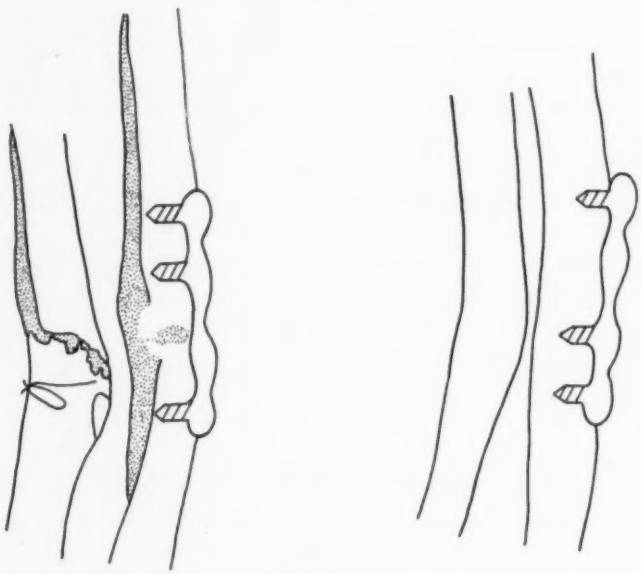

FIG. 12

FIG. 13-A

Fig. 12: Tracings made eight weeks (left) and one year (right) after fixation.
Fig. 13-A: Eight months after insertion of Vitallium plate, insufficient callus was present.

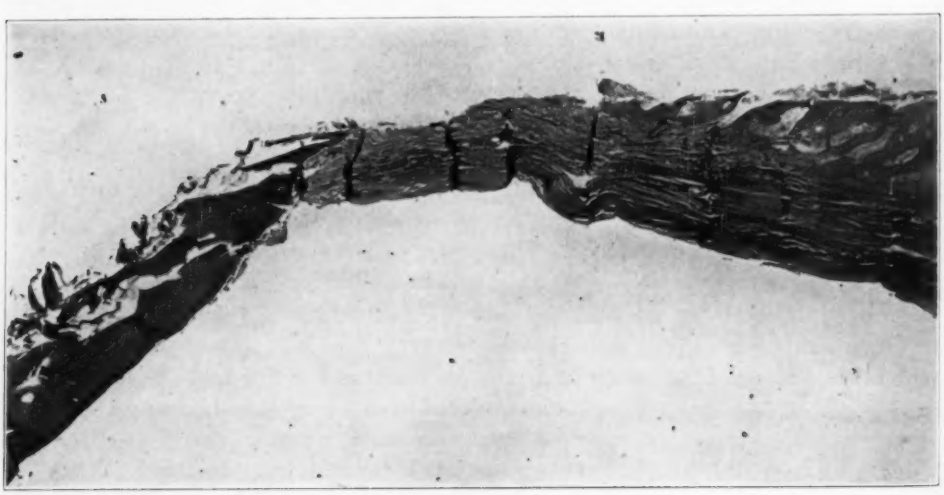

FIG. 13-B

Photomicrograph of section taken at the fracture line of case shown in Fig. 13-A. The trabeculae of the external ossific mass approach, but do not cross, the fracture line.

for having prevented the impaction of the fragment ends. The misinterpretation of such a translucent area has on several occasions, in the writer's experience, led erroneously to secondary operation for suspected delayed union.

CASE REPORT

A woman, aged fifty-four, had sustained a severe closed fracture at the juncture of the upper and middle thirds of the tibia and fibula on April 12, 1945. Because other methods of treatment were ineffective, a six-screw Vitallium plate was inserted on May 3, 1945. Eight months later, the patient was still walking with difficulty in plaster and by the use of crutches, and roentgenograms showed what was considered to be insufficient callus, either external or across the fracture line (Fig. 13-A). It was decided to investigate the fracture with a view to applying a bone graft. At operation, after the plate had been removed, the bone was found to be firmly united. The external mass was represented by a thin shell, reaching approximately the length of the plate. A strip of this, removed for histological examination, showed thin bands of osteoid which approached, but did not cross, the fracture line (Fig. 13-B). No tissue for examination was removed from between the fragment ends, for fear of weakening the union. Its obvious solidity against manual stress was sufficient evidence of effective healing. Following this, the patient remained in bed for two weeks to permit the wound to heal. She was then tested functionally by being urged to bear weight in a walking-iron plaster boot. After a few weeks, since no deformity occurred in the bone, the plaster was removed and unrestricted weight-bearing was encouraged. Because of the prolonged period of restraint, this was difficult for the patient. However, she persisted, and follow-up examination has demonstrated increased density of the fracture site and no subsequent deformity.

COMMENT

The retarded appearance of visible ossification across the fracture space is due to two factors,—one apparent, the other real. The dense shadow ordinarily superimposed over this area by the external ossific mass seen in healing, non-fixed fractures is missing in these cases. In addition, ossific replacement of the soft callus here comes almost entirely from the endosteum and cancellous trabeculae. The customary contribution which permeates the fracture space from the external mass, usually the most rapidly formed, is either absent or minimal. At present, the point in time at which replacement of soft callus by the ossific mass is sufficient to establish effective healing can only be determined grossly by personal experience. Theoretical considerations aside, experience has shown that it is a disservice to the patient, and possibly a deterrent to the later remodeling phase of reparative osteogenesis, to withhold activity or weight-bearing until the translucence of the fracture line has entirely disappeared.

Until some mechanical determinant of resistance to stress and strain is devised which can be applied to the living limb, effective healing must remain a matter of judgment rather than a matter of fact. The cases studied have demonstrated certain observations in restrospect. Our timidity was greater, and consequently the morbidity period of patients following internal fixation was longer, during the earlier years on this Service. As confidence was gained in the use of functional tests with walking irons or crutches, or, in the upper extremity, with guarded activity under observation, morbidity decreased in spite of persistent difficulty with roentgenographic interpretation.

These observations on the pattern of the ossific mass apply only to cases in which internal fixation was efficient,—that is, cases in which full apposition of the fracture surfaces was possible; and screws or plates were inserted in normal bone tissue with correct technique, and were placed in positions which were mechanically sound for the purpose. These principles do not apply when such requirements are not met, as is the case when comminution is extensive, or when the time lag between fracture and operation permits the development of secondary changes on the fracture surfaces. In these latter instances, experience has shown that the criteria of bone healing, as manifested on the roentgenogram, must be those applied to fractures which are not operated upon, and that the density and degree of the external ossific mass are the safest measures of healing. Obviously the

patterns formed are irregular and cannot be presented as types. They are a composite of those required by displacement and by partial fixation.

NOTE: Abou D. Pollack, M.D., of the Department of Pathology, Mount Sinai Hospital, was kind enough to review with the author the histological specimens used in this study.

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HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

DISCUSSION

(*Continued from page 140*)

various items. Much of the discussion has centered about treatment, particularly operative treatment. We deliberately avoided discussion of treatment in our presentation, because we wished to emphasize certain other aspects of the problem: first, that the foot problem is greatly in need of informed study; second, that we lack definite knowledge of the nature of flat feet; and third, that we should seek the important facts which will broaden our knowledge of flat feet. Lacking accurate knowledge, we are prone to resort to hypotheses and, after we have used a hypothesis two or three times, we nearly convince ourselves that it is true and a fact, and then we do not worry to seek facts which will support it.

Further, we wished to emphasize such information as we have been able to obtain by our study regarding the importance of the structure of the foot in maintaining its shape, and particularly in providing support for the rest of the body. Treatment is a broad subject in this kind of flat-foot because, first of all, it is a lesion that is present throughout life. Second, it is a lesion that varies greatly in its severity. There are trivial cases, moderately severe cases, and very severe cases. Third, it produces a varying amount of disability from decade to decade. It bothers the child but little; it bothers the parents more. In adolescence it begins to give trouble. In young adult life it bothers the young man considerably, and certainly it interferes with his function as a soldier. In older life it makes the patient modify his way of living. Therefore, one cannot be dogmatic about treatment, so we purposely avoided a discussion of treatment in our paper. We think surgical treatment should be used in the severe cases, and that it should be used as early as possible without producing serious trouble. We have an operation, similar to the one Dr. McDonald described, which we have been using and which we think is good.

The study in the Canadian Army, from which much of this information was obtained, was very much broader than this particular problem, as it included all foot problems of men in military training. It was of value in determining what the foot problems were in a certain cross section of the male population in Canada, in what numbers they occurred, and what they meant for these young men as soldiers. Should anyone like to read the report of this study, it will be published shortly by the National Research Council of Canada. It is not very easy reading, but it does contain an enormous amount of observed facts, and it may be of value in the estimation of these problems.

CYST-LIKE LESIONS OF CARPAL BONES, ASSOCIATED WITH UNUNITED FRACTURES, ASEPTIC NECROSIS, AND TRAUMATIC ARTHRITIS

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It is a matter of common knowledge that cyst-like areas of bone absorption occur about the hip in degenerative conditions of the joint. These are seen in malum coxae senilis, but have also been observed following fractures of the femoral neck and traumatic dislocations of the hip, which produce necrosis of the femoral head; in Legg-Perthes disease; and in epiphyseolysis. Similar areas of bone absorption have been observed in many instances about joints, other than the hip joint, that are the seat of degenerative disease.

Few references to the occurrence of such lesions about the wrist, in degenerative conditions of the radiocarpal and carpal joints, are to be found in medical literature, although such lesions are not uncommon. Bunnell, in the section of his book devoted to traumatic degeneration of carpal bones, presents roentgenograms of cyst-like areas in the scaphoid, lunate, capitate, and triangular. In each case, trauma appears to have been antecedent to the onset of symptoms in the wrist. Bunnell seems to favor the theory that there has been a disturbance of the blood supply to the affected bones.

The histories of three patients with such lesions of the carpal bones, who were operated upon at the University of Chicago Clinics, are presented:

CASE 1. O. T., a meat cutter, aged fifty-eight, was first seen in the Clinics on March 1, 1937, complaining of pain and swelling of the right wrist, which had been present for from four to five weeks. No injury was remembered, but, for from ten to twelve years, this wrist had been thicker than the other. The patient was right-handed and had used a cleaver steadily at his work. Physical examination showed that the right wrist was one centimeter greater in circumference than the left. There was no limitation of motion in the wrist, but slight grating was noted. Laboratory examinations, including the Kahn test, were negative. Roentgenograms of the wrist (Fig. 1-A) showed a large cyst-like area of central absorption in the capitate, and a smaller area in the triangular. There was no sclerosis of the surrounding shell of bone. The cartilage of the radionavicular articulation was narrowed, and the cortex of the bones was obscured. At operation on May 20, 1937,

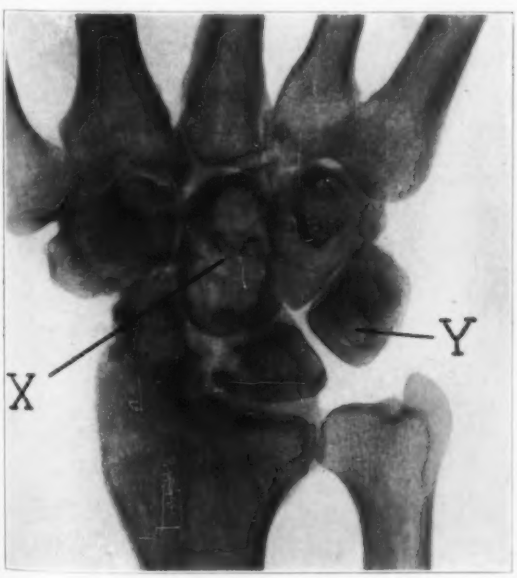

FIG. 1-A

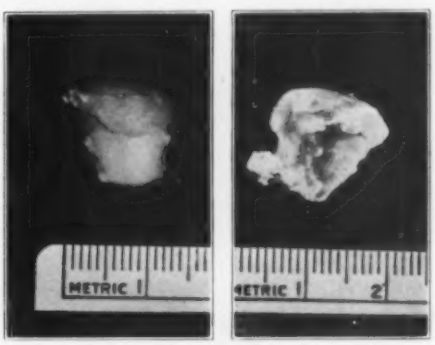

FIG. 1-B

Fig. 1-A: Case 1, O. T. Aseptic necrosis and central absorption of capitate, *X*. Central absorption in triangular, *Y*. Chronic arthritis in wrist with narrowing of cartilage space between radius and navicular.

Fig. 1-B: Views of the excised proximal portion of the capitate.

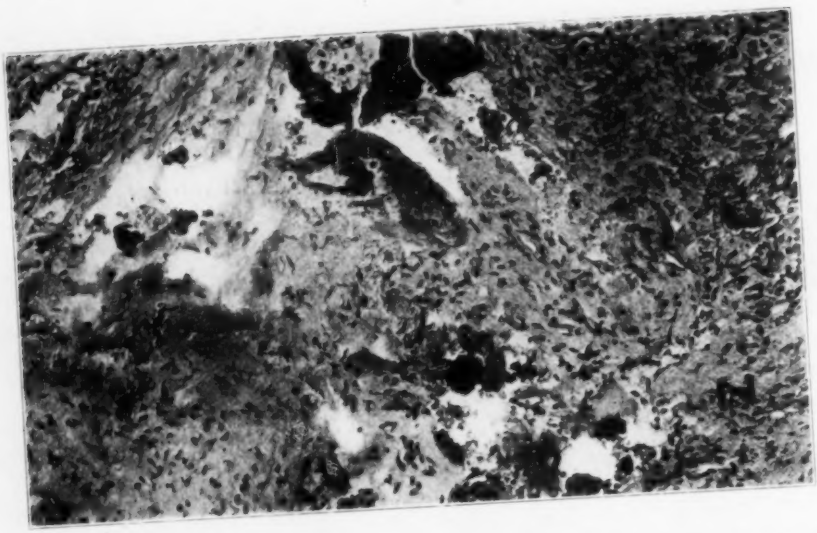

FIG. 1-E

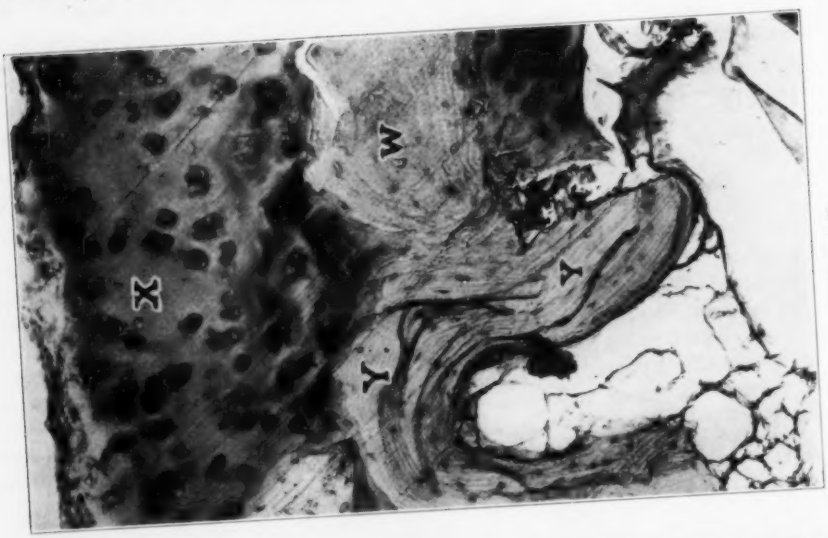

FIG. 1-D

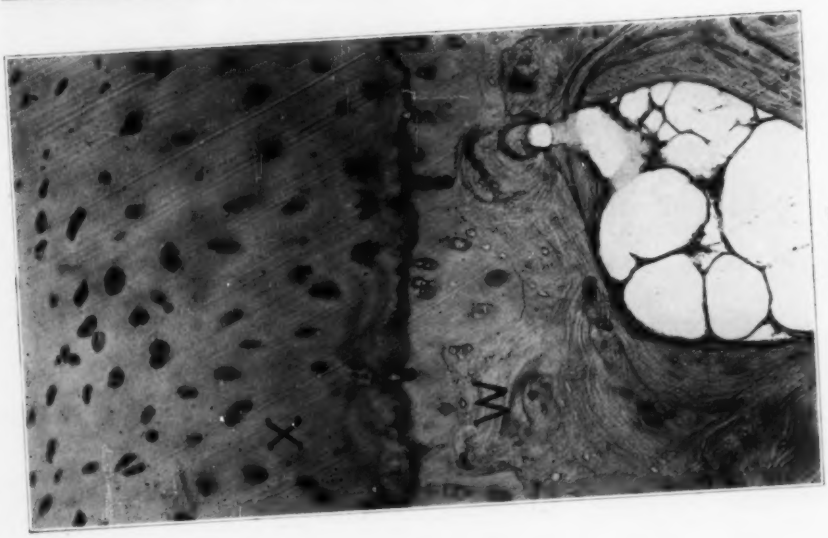

FIG. 1-C

Microscopic sections of excised portions of capitate.
Fig. 1-C: Cortex with necrotic bone, *W*, and feebly staining articular cartilage, *X*.
Fig. 1-D: Region of cortex undergoing creeping substitution. Cartilage, *X*, being replaced by fibrocartilage, and dead bone, *W*, being replaced by new bone, *Y*.
Fig. 1-E: Fibrous tissue, *Z*, which occupied central portion of capitate, is partly calcified.

the capitate was exposed through a dorsal incision, and an old fracture, with a narrow line, was found in the cortex at the margin of the proximal articular cartilage. It had obviously occurred secondarily, after central absorption of the bone. A window was excised, which exposed a large cavity filled with fibrous tissue, yellowish necrotic material, and a small amount of fluid. The contents were curetted out. Inspection of the proximal articular surface revealad that it was yellowed, mottled, and apparently dead. The dorsal part of the proximal end of the bone was, therefore, removed (Fig. 1-B), and the wound was closed. Smears of the joint fluid showed many polymorphonuclear cells and lymphocytes. Cultures of this fluid showed a growth of *Staphylococcus albus* after forty-eight hours. This was probably a contaminant, since cultures of fluid from the cyst showed no growth. Guinea pigs inoculated with fluid and necrotic tissue from the cyst showed no evidence of tuberculosis. Microscopic sections of the excised tissue (Figs. 1-C, 1-D, and 1-E) showed that the cyst was occupied by partially necrotic and calcified tissue. The shell of bone surrounding it consisted, in part, of necrotic trabeculae, which were undergoing replacement by new bone in some areas. The articular cartilage of the excised proximal fragment of bone stained poorly; it had been partially replaced by fibrocartilage. The bone underlying this cartilage was necrotic. A portion excised from the anteroproximal part of the capitate showed living bone, covered by fibrocartilage. The postoperative course of the patient was uneventful. A splint was worn for four weeks. The patient returned to work two months after the operation, with the wrist practically free from pain and two thirds of the normal motion present. He has continued to work, but has avoided strenuous use of the hand, and has had no further difficulty. Figure 1-F shows the condition of the wrist three years after the operation.

FIG. 1-F

Three years after Fig. 1-A. Wrist is symptom free. Arthritic changes in radionavicular joint. Cavity, *Y*, persists in triangular.

CASE 2. G. H., a housewife, aged fifty-seven, was first seen in the Clinics on April 4, 1944, complaining of intermittent periods of pain and swelling of the left wrist, which had been present since a fall on the outstretched hand thirty years before. There was pain and swelling for some time following the original injury, but no medical attention was sought. Subsequently, too active use of the hand resulted in recurrences of pain and swelling of the wrist. Physical examination revealed swelling over the dorsum of the wrist and marked limitation of motion. Roentgenograms (Fig. 2-A) showed a cyst-like area, without sclerosis about it, occupying the proximal two thirds of the capitate. The navicular was in two parts; the proximal part was narrowed and deformed. There were well-developed degenerative changes in the radiocarpal joint. A fracture of the navicular appeared, therefore, to have occurred, with aseptic necrosis of the proximal fragment; nonunion; subsequent collapse of the fragment, and its transformation; and secondary arthritis. Laboratory examinations were negative. At operation on April 14, 1944, a partial ostectomy of the capitate and curettage of the cyst were done through a dorsal exposure. Microscopic examination of the excised tissue (Figs. 2-C and 2-D) showed that the cyst was lined by fibrous tissue of varying cellularity. Bits of bone were found in the fibrous tissue. The surrounding bony trabeculae were for the most part normal, although there were a few subcortical areas of dead bone being replaced by living bone. The articular cartilage showed degenerative changes, with extensive replacement by fibrocartilage and fibrous tissue. A plaster splint was applied to the wrist, following the operation, and was worn for four weeks. The wound healed promptly. Considerable restriction of motion in the wrist persisted, but function improved. One of the roentgenograms, taken two months after the operation, is shown in Figure 2-B.

CASE 3. H. W., a steamfitter, aged thirty-five, was first seen in the Clinics on January 9, 1946, complaining of intermittent pain in the right wrist, which had been present since an injury incurred in a football game twenty-one years before. The wrist was swollen and painful after the injury, but symptoms subsided in a few weeks, to become aggravated again whenever hard work was done. Roentgenograms had been taken in 1943, and these showed that the navicular was in two parts, but there was no evidence of necrosis of the

proximal fragment. There was cystic rarefaction of the lunate, with a shell of sclerotic bone about the cyst. A small loose body was seen near the navicular, and there were tiny osteophytes along the articular surface of the radius. Roentgenograms, taken at the time of admission to the Hospital (Fig. 3-A), were essentially similar to the earlier roentgenograms. Physical examination showed slight swelling of the wrist, weakness of grip, and pain on hyperflexion and hyperextension of the wrist. The blood Kahn test was negative, as were other laboratory examinations. At operation, the lunate and navicular were exposed through a dorsal incision. The synovial lining was hypertrophied. A pedunculated osteocartilaginous loose body was removed from the junction of the lunate and capitate. The fragments of the navicular appeared to be viable, and were not disturbed. The cyst of the lunate was opened. It contained a small amount of fluid and a large amount of fibrous tissue, which was removed with a curette. Cultures of the fluid from the cyst showed no growth. Microscopic sections of the excised tissue (Figs. 3-D and 3-E) showed that the bony trabeculae in the wall of the cyst were for the most part necrotic. The fibrous tissue of the cavity was also extensively necrotic, and small areas of calcification were evident. The wrist was immobilized in a plaster cast for four weeks after the operation. One of the roentgenograms taken three and one-quarter months after the operation is shown in Figure 3-B. A roentgenogram taken ten months after the operation (Fig. 3-C) showed persistence of the defect in the lunate. The area of reduced density in the proximal half of the capitate appeared to be a trabecular configuration, but may have been a new cyst. When these roentgenograms were taken, the wrist was entirely painless, and a full range of motion was present.

DISCUSSION

In two of the three cases here presented, symptoms dated from an injury to the wrist, and in each there was an ununited fracture of the navicular of long standing. In Case 2, necrosis of the proximal fragment of the navicular, with subsequent collapse or compression, had evidently occurred. In each case, sufficient time had elapsed for advanced revascularization and replacement of the necrotic bone. In Case 1, which involved the capitate, there was no definite history of injury, but the man was a meat cutter, and repeated small traumata of the bone had probably occurred. In all three, there was histological evidence of aseptic necrosis in the shell of bone about the cyst. Factors other than trauma may play a role in the etiology.

The changes undergone by necrotic bone and cartilage, following interruption of the blood supply to the head of the femur, have been described by Axhausen, Phemister,

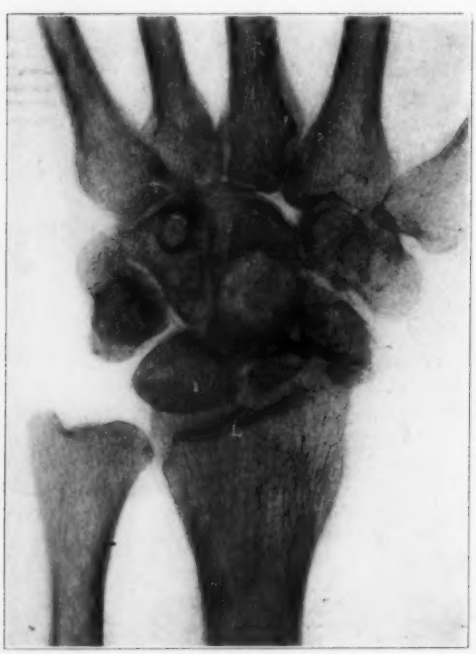

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 2, G. H. Area of central absorption in the capitate. Old ununited fracture of the navicular. Arthritic changes in the radionavicular joint.
Fig. 2-B: Two months after Fig. 2-A, and after partial excision of the capitate.

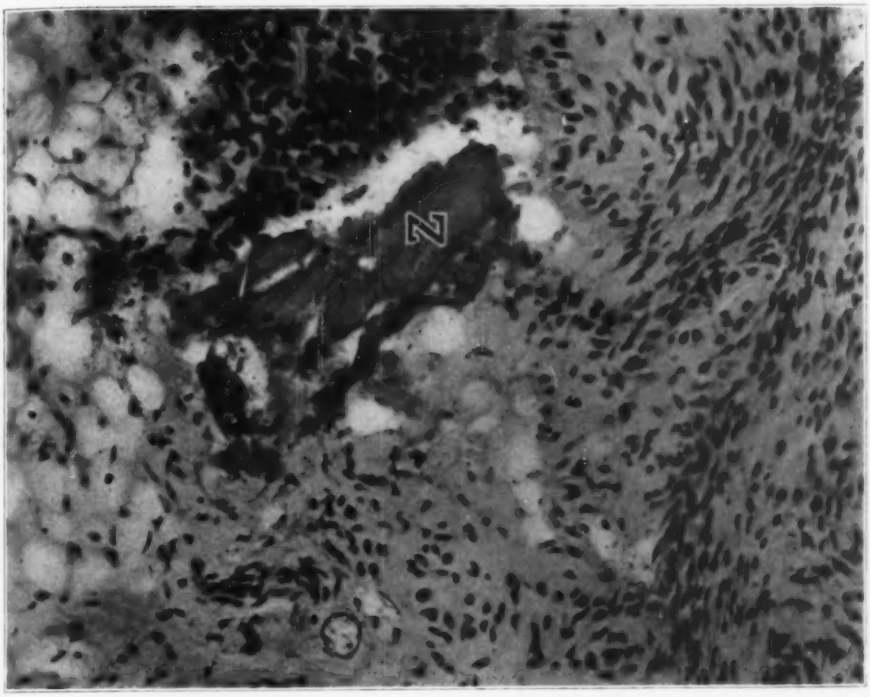

FIG. 2-D

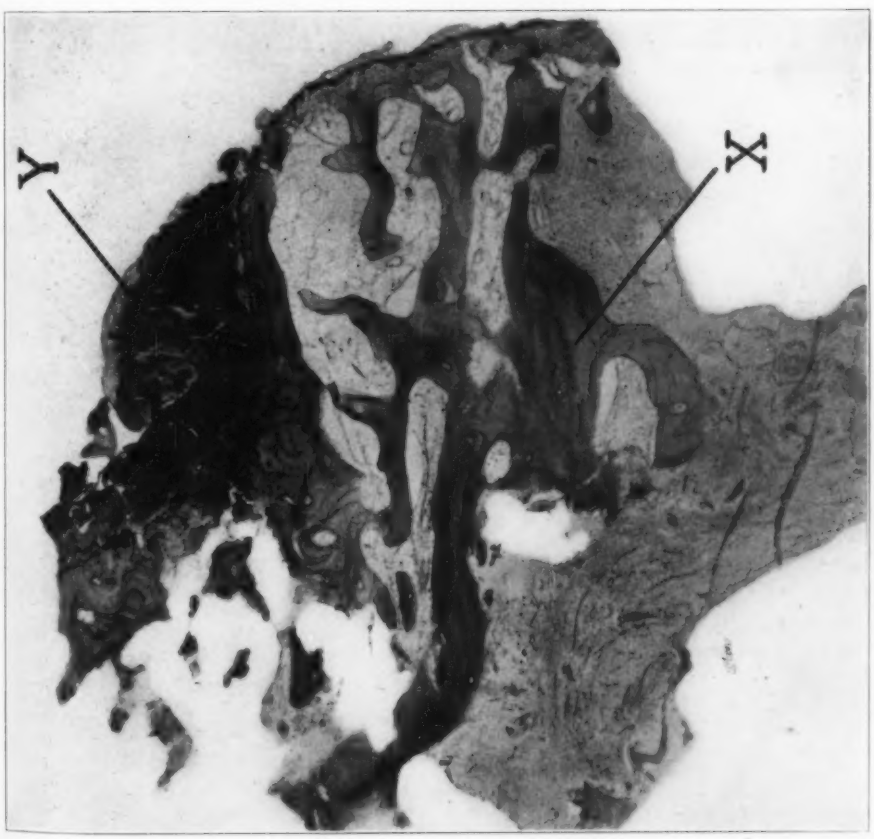

FIG. 2-C

Microscopic sections of the excised portions of the capitate.

Fig. 2-C: Wall of cyst-like area, showing trabeculae of bone, *X*; degenerating cartilage, *Y*; and fibrous tissue, filling defect in bone.

Fig. 2-D: Fibrous tissue from area of bone absorption, with small fragment of necrotic bone, *Z*.

and others. The necrotic epiphysis may undergo progressive and complete replacement by living bone. Usually, replacement is irregular and incomplete. Areas of necrotic bone may be absorbed and replaced by fibrous tissue, without subsequent replacement by living bone. These are the cysts seen late in the process. Articular cartilage degenerates and is replaced to a varying degree by fibrocartilage and fibrous tissue.

FIG. 3-A

Case 3, H. W. Aseptic necrosis and central absorption of lunate. Old ununited fracture of the navicular. Roentgenograms taken three years before showed same changes.

FIG. 3-B

FIG. 3-C

Fig. 3-B: Four months after Fig. 3-A, and three and one-quarter months after excision of dorsal window and curettage of the lunate. Wrist is symptom free.
Fig. 3-C: Ten months after operation. Wrist is painless.

FIG. 3-E

Dense, partially calcified, fibrous tissue excised from central area in lunate.

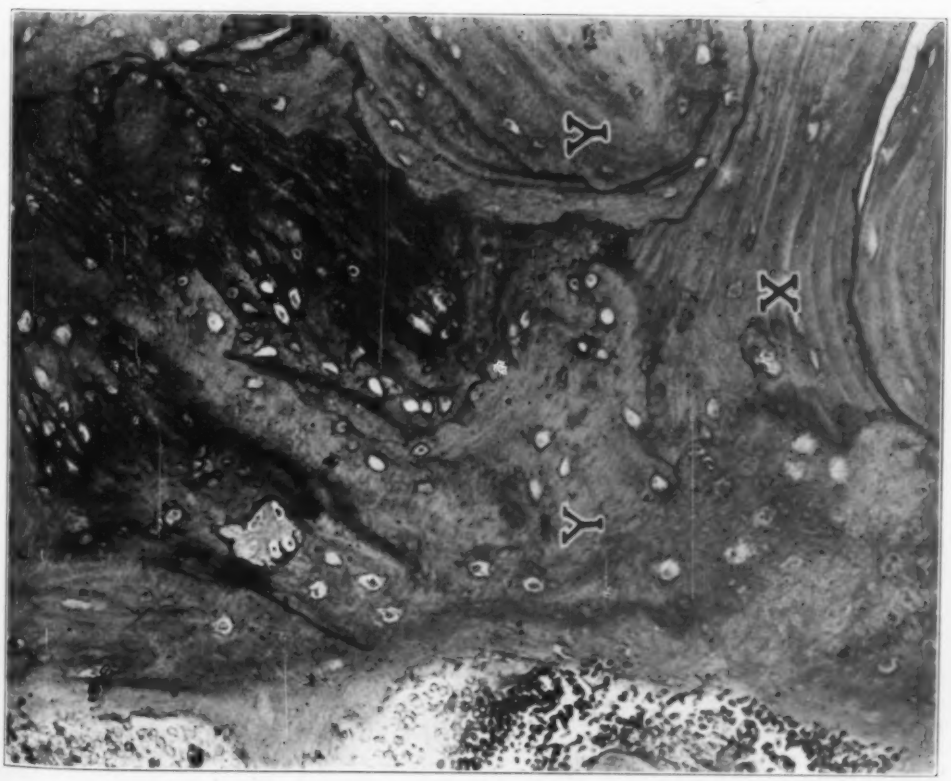

FIG. 3-D

Wall of cyst-like area in lunate. Necrotic bone, *X*, undergoing creeping substitution by living bone, *Y*.

Pathologically, the cyst-like areas of rarefaction in the carpal bones resemble the cysts of the capital femoral epiphysis, and their pathogenesis may be assumed to be essentially the same. They also bear some resemblance to subcortical cyst-like areas in the femoral head and in the acetabulum at the weight-bearing region in chronic degenerative arthritis. The severity of symptoms in these cases is probably dependent upon the severity of the associated degenerative arthritis. Surgical treatment is beneficial, but cannot be expected to provide complete relief from symptoms.

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CARTILAGE AND CHONDROITIN SULPHATE

III. Chondroitin Sulphate and Inflammatory Lesions of Cartilage *

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The current literature contains discussions of the gross morphology of some inflammatory lesions of cartilage, resulting in cartilage destruction. Knowledge is, however, very meager as to the minute details of the actual changes in cartilage during these conditions, and all contributing factors are not known. To judge from earlier investigations, which will be mentioned later, more exact data are needed as to the content of chondroitin sulphate. In the present communication some additional data are supplied, and an attempt is made to correlate general biochemical characteristics of inflammatory changes with the morphological details of cartilage destruction due to inflammation.

Whether or not exudative non-infectious *synovitis* induces any changes in articular cartilage seems to be unknown, and will not be taken into consideration in this paper.

The changes in acute *infectious arthritis* vary according to the type of agent[3]. For example, rapid and complete cartilage destruction is seen in gonorrheal arthritis, while mild destruction or almost none at all is encountered in other types of arthritis. In the first classical description, Virchow stressed the breaking up of the intercellular matrix.

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This process was studied in more detail by Axhausen and Hellner[7], who described the destruction of cartilage by leukocytic action. The content of chondroitin sulphate did not attract any attention, but it seems fair to suppose that the early disappearance of chondroitin sulphate is a distinctive feature of infectious cartilage destruction[8].

In chronic *rheumatic arthritis*, focal cartilage degeneration (hyaline or fibrinoid) has been reported by Klinge, probably preceded or accompanied by a disappearance of chondroitin sulphate. Definite statements are lacking, but the suggestion mentioned gains some support by Hirsch. When considering this disease, we should bear in mind the multitude of factors involved, which include synovitis, altered composition of the synovial fluid, impairment of function, and formation of adhesions.

Regarding *tuberculous arthritis*, Heile, using polychrome methylene blue, reported the early disappearance of the typical metachromatic staining reaction of the intercellular matrix, whereby the collagenous fibrils were unmasked. Similar findings were published by Seggel, who also observed incidental remains of metachromatic material in areas surrounding degenerating chondrocytes. In a general way, the tuberculous cartilage destruction has been ascribed to the action of granulation tissue (leukocytes and lymphocytes) and of ingrowing connective tissue ("pannus")[6].

Various inflammatory lesions of other types of cartilage have been studied, but no attention has been paid to the content of chondroitin sulphate. The end result of such infections is usually cartilage necrosis.

The general conception is that cartilage presents a remarkable "resistance" to infection, which is perhaps partly attributable to its avascularity. Obviously, an exception must be made for the inflammations due to certain bacteria, such as *Neisseria gonorrhoeae*.

There are many possible factors responsible for the cartilage destruction due to inflammation; some of the most important will be mentioned. Thus, in the course of inflammatory lesions, changes occur in the hydrogen-ion concentration[11,12] and in the flow of blood and tissue fluid; and groups of different enzymes are interacting. Furthermore, cartilage cells are opposed to granulation tissue, containing fibroblasts and wandering cell elements. In a general way, we are justified in stating that the inflammatory processes create a new and different medium, containing biochemical factors liable to alter the normal conditions of cartilage physiology and nutrition. The deleterious effect of growing fibroblasts, as seen in tissue culture, might also be recalled[13].

MATERIAL AND RESULTS

For lack of sufficient material, only a small number of cases have been investigated. With the use of a correct metachromatic staining technique, according to Lison[10,15], the content of chondroitin sulphate has been estimated, and its distribution has been ascertained. Some technical data and the main results are summarized in Table I.

To judge from the material taken from patients with tuberculous arthritis and osteochondritis (Table I), it seems evident that cartilage alterations are gradual and may be divided into two phases. The first phase of inflammatory derangement of cartilage is characterized by a demonstrable decrease in the content of chondroitin sulphate of the intercellular matrix, which in other respects seems quite normal. This condition is found in cartilage areas adjacent to actual inflammatory foci, but not yet subjected to the inflammatory changes. Thus, in this stage no appreciable oedema or inflammatory cells are seen. The second phase involves the actual inflammatory changes with cell infiltration, granulation tissue, ingrowth by fibroblasts, and subsequent necrosis and digestion of cartilage. In this stage of alterations, usually no chondroitin sulphate can be demonstrated in the markedly changed intercellular medium. Yet, cartilage on the verge of necrosis may show thin pericellular halos of metachromatic stainability, indicating remains of chondroitin sulphate.

According to the observations of Hirsch, the focal lesions of joint cartilage in rheu-

TABLE I

THE ESTIMATED CONTENT OF CHONDROITIN SULPHATE IN CARTILAGE SUBJECTED TO INFLAMMATORY CHANGES

Material *	No. of Cases	Estimated Content of Chondroitin Sulphate
Tuberculous arthritic tissue (knee and hip)	7	*Normal cartilage:* Large content of chondroitin sulphate. *Inflammatory foci:* 1. In the surrounding, slightly oedematous, cartilage areas, without actual signs of inflammation, a gradual decrease in chondroitin-sulphate content was observed toward the inflammatory focus. 2. In the periphery of the lesions, slight and beginning inflammation was present, characterized by exudation and leukocytic infiltration; a small amount of chondroitin sulphate was observed. In places, chondrocytes with pericellular halos of metachromatic material were seen. 3. In the center of the focus, with marked inflammatory signs and cartilage destruction, the metachromatic material was lacking. 4. Necrotic cartilage was devoid of the metachromatic staining reaction.
Tuberculous osteochondritic tissue (ribs)	3	Same findings as above
Tissue of chronic perichondritis (ear cartilage)	2	Sclerosis and slight lymphocytic infiltration of the perichondrial connective tissue. No inflammatory changes in the cartilaginous tissue itself. In its superficial zone, the ear cartilage lacks chondroitin sulphate. Somewhat deeper, toward the center of the cartilage, an increasing content is seen.

* Fresh material, obtained at operation, was used, fixed in 8 per cent. formaldehyde solution. Sections, measuring 5 micra, were stained in 0.1 per cent. toluidine-blue solutions in alcohol at concentrations of 1 per cent., 30 per cent., and 50 per cent.

matic disease and infectious arthritis are also accompanied by a corresponding local decrease in the chondroitin-sulphate content, as stated.

The effects of chronic perichondritis were studied in ear cartilage (Table I). Fibrosis and lymphocytic infiltration of the perichondrium evidently induce a moderate decrease in the content of chondroitin sulphate in the superficial part of the underlying cartilage. It may also be mentioned that small superficial erosions of ear cartilage, filled by growing perichondrial fibroblasts, were found to evoke a similar decrease in ester-sulphate content of the neighboring cartilage zone.

To sum up, it seems evident that the very first sign of inflammatory derangement of cartilage, hitherto described, is a moderate decrease in the content of chondroitin sulphate, preceding the actual inflammatory lesions. This early loss of ester sulphate must be induced by the inflammatory process under question. The remaining bulk of chondroitin sulphate is rapidly lost when the advancing inflammatory process becomes established.

It should be noted, however, that, in the course of inflammation, cartilage does not present any signs of "dedifferentiation" or of regenerative proliferation. No indications of repair by transformation of perichondrial or other fibroblasts were observed [4].

DISCUSSION

Considering the active factors responsible for inflammatory destruction of cartilage, all possible interpretations will be defective for lack of sufficient data. However, in some respects the available observations afford a basis for some simple deductions. From an academic point of view, two separate stages of cartilage changes were distinguished: (1) a

gradual loss of chondroitin sulphate, preceding the actual inflammatory changes; and (2) the actual destruction and digestion of cartilage substance. Some conditions favor the opinion that these processes are effected by different chemical factors.

In conformity with the opinions presented in the first paper of this series [15], we have to emphasize the fundamental importance of the acid reaction of the intercellular medium in normal cartilage. From the works by Menkin on the chemistry of inflammation, we know that the hydrogen-ion concentration of the infectious foci must be near pH 7, or slightly on the alkaline side. Recalling the sensitivity of the native chondroitin-sulphate molecule to slight alkaline reactions [2], we thus arrive at the following explanation as being most likely: It seems probable that the gradual loss of chondroitin sulphate, as stated, constitutes a manifestation of a *gradual alkaline depolymerization and disintegration* of the molecule under question, effected by a peripheral spread (diffusion) of alkaline material from the central focus of inflammation. Other cooperating factors must not be overlooked, such as the possible effects of proteolytic and other enzymes, produced by growing fibroblasts, bacteria, or inflammatory cell elements; and further, a diminished production of chondroitin sulphate, either alone or in combination with an increased absorption. Among the enzymes, the possible role of hyaluronidase has been mentioned [15].

In the author's opinion, the inflammatory shift in pH toward the alkaline side, as discussed by Menkin, may be the chief operating factor responsible for the decomposition, or disappearance, of chondroitin sulphate. This factor has been omitted in previous discussions concerning morphological changes in cartilage.

Considering the second phase, characterized by digestion of the cartilaginous matrix and cell bodies, the action of proteolytic enzymes must be postulated. Such enzymes may be delivered by the different cell types of the granulation tissue. The cultivation experiments of Roulet also call attention to the biological effect of growing fibroblasts on cartilage.

As regards the sequelae of inflammatory derangement of the perichondrial connective tissue, it seems quite clear from the present results that such changes are capable of inducing a depletion of chondroitin sulphate in the underlying cartilage area. Recalling the function of the perichondrium [15], we may suggest that this loss of ester sulphate could be a manifestation of impairment of nutrition in the corresponding cartilage. However, this question cannot be decided for lack of additional data. Once more, the observation of small superficial erosions, evoked by ingrowing fibroblasts (Table I), requires attention as to the behavior of fibroblasts against cartilage [13].

From a physiopathological viewpoint, the present results seem to require further attention. Considering the strongly acid reaction of the normal intercellular cartilage matrix [15], and recalling that a neutral or slightly alkaline reaction is a prerequisite for the propagation of inflammation [11, 12], we are justified in suggesting that chondroitin-sulphuric acid, by its acid reaction, affords a protective action against the spread of inflammatory lesions. Judging from the present results, I venture the statement that the disintegration of chondroitin sulphate is a prerequisite for the propagation of inflammation in cartilage. The possibility of an alkali-binding function of chondroitin-sulphuric acid (or of its degradation products) must also be considered. Thus, these deductions lend some interpretation to the well-known "resistance" of cartilage to inflammation.

In the first paper of this series, the deficiencies of the present purely morphological conceptions of cartilage were considered. Before further progress can be made, we evidently must gain new and more correct insight into the normal physiology of cartilage. In the author's opinion, a correct basis for future research will be obtained by applying the present knowledge of the chemical and physical characteristics of chondroitin-sulphuric acid. This acid substance seems to afford a key to most of our current problems concerning cartilage physiology and physiopathology. This opinion is supported by the present studies on the physiological ossification and the inflammatory changes of cartilage.

SUMMARY

By means of a correct metachromatic staining technique, the distribution of chondroitin sulphate in cartilage during inflammatory conditions has been described. The results support the following conclusions:

Preceding the actual inflammatory changes, a decrease in the content of chondroitin sulphate was ascertained. Most of the ester sulphate is lost when the inflammatory changes become established. The observed depletion of chondroitin sulphate is probably effected by an alkaline depolymerization and disintegration of the molecule in question. Among different contributing factors, the alkaline hydrogen-ion concentration in inflammation seems to be of prime importance for the interpretation of the observations. The disintegration of the ester sulphate seems to be a prerequisite for the propagation of the inflammatory process in cartilage, and this in part explains the "resistance" of cartilage.

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PLASTIC REPAIR OF THE EXTREMITIES BY NON-TUBULATED PEDICLE SKIN FLAPS

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In wounds and burns of the extremities, a variable amount of tissue damage is produced. Experience has shown that wounds should be closed, and a skin covering should be obtained as soon as it is feasible, in order to eliminate infection and to minimize the formation of scar tissue. Gaping of wounds is caused by the eccentric pull of the surrounding elastic tissue and by the release of the continuous tension of the deep fascia. When the loss of skin and subcutaneous tissue is more apparent than real, closure by primary suture or by late primary suture may be possible. However, when there is loss of skin, the raw area must be covered by a free skin graft or by a pedicle skin flap. This principle is generally understood and applied. Over many wounds the free skin graft provides not only the immediate "skin dressing", but also an enduring surface repair. Under certain circumstances, however, free skin grafts are unsatisfactory, and the covering of the wound by a pedicle skin flap is required. The study of the indications, the applications, and the technique of using non-tubulated pedicle flaps constitutes the object of this paper. Observations have been made in a series of 781 pedicle-flap operations, performed by the author during the past six years, for the resurfacing of defects, resulting from traumatic injuries of the extremities.

SKIN GRAFTS AND SKIN FLAPS: THEIR RESPECTIVE INDICATIONS

The technique of skin-grafting is relatively simple, but skin grafts often fail to "take" satisfactorily when placed over poorly vascularized areas, and give poor protection to certain underlying structures, as they are comprised only of the epithelium and a portion of the dermis. Skin-grafting is a method of *immediate* transplantation of skin.

Pedicle flaps differ from skin grafts in their anatomical structure, since they are formed, not only of epidermis and dermis, but also of subcutaneous fat. They constitute a method of *intermediate* [1] skin transplantation, because at first the pedicle provides nutrition to the flap through its arteries, veins, and lymphatics. After a few days, the flap acquires vascular connections with the underlying bed. Later, after the softening of the peripheral scar, it receives vessels from the surrounding tissue. Thus a flap may survive, even over a surface presenting poor vascularization. The layer of adipose tissue in the flap provides elasticity and extensibility, permitting a certain degree of stretching over the surfaces of joints. It is also shock-absorbing, and resists the stress of weight-bearing, of shoe-wearing, and of commonplace trauma. Subjacent tendons may glide through this fat layer of the flap, which prevents the recurrence of scar tissue after the latter has been entirely resected. Therefore, when skin grafts are unsatisfactory, skin flaps are indicated.

Free skin grafts are unsuitable in five sets of circumstances:

1. *For Covering Densely Scarred Areas*

The complete "take" of a skin graft cannot be assured, when it is applied over a poorly vascularized surface, containing scar tissue which it has not been possible to resect entirely, either because the scar merges onto a joint capsule or bare bone, or because it incorporates large vessels or nerves. In such cases, even after an immediate "take", the free skin graft may break down secondarily. This complication is seen particularly when the free graft covers an area of functional stress,—such as a joint like the elbow or the knee, or a weight-bearing area of the foot.

2. *For Covering Bone*

Free skin grafts will take well over healthy periosteum and will resist ordinary trauma, if they are not placed in positions of functional stress. A free skin graft does not constitute a covering which will permit a secondary operation,—such as bone-grafting or a joint resection. A free skin graft receives little blood supply from the surrounding tissue, so that it cannot be raised from its bed without danger of necrosis. Bare bone, if it is to survive, must be covered by well-vascularized integument. It should be covered at the earliest moment by a pedicle skin flap to prevent ischaemic necrosis, elimination of bone, possible infection, osteomyelitis, and sequestration.

3. *For Covering Tendons*

Tendons must be placed among tissues which permit gliding,—tendon sheath, paratenon, loose cellular tissue, or fat. In repairing tendons or freeing tendons which are bound in an overlying cutaneous scar, the importance of removing all of the surrounding scar tissue and of covering the tendons with the adipose tissue of a pedicle flap cannot be overstressed. These constitute the condition *sine qua non* for the success of tendon plastic surgery. Tendons, even when they have been carved out of a solid block of surrounding scar tissue, may glide, if they are surrounded by fat or loose cellular tissue.

4. *In Peripheral-Nerve Surgery*

A missile may cause injury not only to the bones, tendons, muscles, or skin and subcutaneous tissue, but also to adjacent peripheral nerves. It has become increasingly apparent that, in such cases, the covering of the nerve by normal, well-vascularized skin and subcutaneous tissue is an essential part of the peripheral-nerve repair for the following reasons:

a: A nerve constricted by scar tissue loses its conductivity. If the nerve is anatomically intact, freeing it from the constricting extrinsic scar will usually hasten its recovery and will seldom retard it. If the severed nerve must be sutured, it is essential that the return of conductivity be unhampered by the scar.

b: The covering scar tissue may provide inadequate protection to the nerve, when it is superficial. The injured nerve may become superficial in position, as a result of the destruction of overlying muscles. In healed wounds of the posteromedial aspect of the elbow, the ulnar nerve may lie immediately beneath the scar tissue or may even be incorporated in the scar itself.

c: Pain may be caused by the presence of scar tissue around a nerve. Sensory fibers from the nerve may become incorporated in the overlying scar, thus constituting a painful scar. Such "intracutaneous neuromata" can be cured only by total excision, and replacement of the scar containing the constricted sensory-nerve endings. A flexor tendon may become adherent to the median nerve, causing pain by pulling on the nerve in the course of its excursion, until the nerve is freed from the binding scar. Many incomplete nerve injuries are associated with causalgia-like pains, which may be relieved by the dissection of the extrinsic scar and by placing the nerve in a new bed, where it is surrounded by normal tissue. Pedicle flaps of skin, transplanted over the nerve, give the latter a well-vascularized protective covering, which a free skin graft fails to provide.

5. *When Secondary Operations Are Necessary in the Repaired Area*

An area in which an operation upon the bones, the tendons, the ligaments, or the joints must be performed, or through which it is desired to explore a peripheral nerve, must be covered by a skin flap, which alone will be sufficiently resistant to withstand the incisions, the undermining, and the unavoidable manipulations of the operation. The use of skin flaps also permits combined simultaneous operative procedures on tendons or nerves, the overlying defect being immediately covered by a pedicle flap of skin.

GUIDING PRINCIPLES IN PEDICLE SKIN FLAPS

After transplantation, the flap must live on its pedicle until, through a process of granulation, new vessels have grown into the under-surface of the flap from the recipient bed.

The width of the pedicle must be sufficient to ensure arterial supply and venous and lymphatic return. In an immediately transferred flap, unless the flap contains a large arterial and venous supply, its length should not exceed one and one-half times its width.

Incisions outlining the flap should be carried down to deep fascia, and the flap should be raised by separating the fat from the fascia. In this manner, injury to the main nutrient vessels traveling through the fat is avoided. The disparity of thickness of a transplanted flap and the surrounding tissue may be a temptation to thin down the fat layer at operation. Only experience can guide in the extent of the resection which may be thus practised, because of the danger of injuring the nutrient vessels. The line of attachment of the flap should cut across the general direction of the vessels, so as to receive the greatest possible blood supply. Skin flaps may be taken from the immediate vicinity of the defect, or from a distance from the defect. The former are called local (or contiguous) flaps.

LOCAL FLAPS

The possibility of shifting tissue by local flaps is explained by the natural elasticity of the skin, which permits its adaptation to new positions. At no time, however, should this elasticity be abused, so that the flap is made to assume its new position under tension. Whenever the defect to be covered is not too extensive, and when sufficient tissue is available in the vicinity of the defect, its repair by local flaps is to be preferred. The technique is simple and rapid in comparison to that of transferring a flap from a distance. Local flaps generally give a more suitable repair, because adjacent tissue is employed. When the surrounding tissue is very loose, particularly in older individuals, it is possible to undermine the skin edges around the defect by freeing the fat layer from the fascia. This undercutting permits the stretching of the skin in straight-advancement flaps. However, it must be stressed that the proper use of local flaps implies the mobilization of skin from an area adjacent to the defect, in such a manner that the secondary defect produced may be closed without causing tension upon the suture line of the primary defect. To achieve this, it is necessary to shift the flap through an angle approaching 90 degrees. When the secondary defect cannot be closed by direct approximation, the flap must be taken from an area upon which a free skin graft can be applied without causing any functional disturbance. Often an advantageous barter of tissue can be carried out,—for example, when a flap is raised to cover a tendon, and the secondary defect is repaired satisfactorily by a free skin graft (Figs. 1-A, 1-B, 1-C, and 1-D).

Local flaps fall into one of two main types,—transposed flaps and rotation flaps.

1. *Transposed flaps* are raised at an angle to the defect and are then applied over the latter (Figs. 1-A, 1-B, 1-C, and 1-D). Such a flap should be borrowed from an area where tissue is abundant, so that a direct closure of the secondary defect may be possible (Fig. 2). By a procedure of double transposition, popularly known as "Z flaps", shortness of skin, resulting in contractile bands of scar tissue, can be remedied. Bipedicle transposed flaps are less mobile than unipedicle flaps, and are more limited in their use. They find their best application when their transfer is effected by a change of plane (Fig. 3).

2. *Rotation flaps* permit the shifting of adjacent tissue along a curved line, on which the tension is evenly distributed. There are two varieties of rotation flaps,—the swinging-rotation flap (Fig. 4), and the advancement-rotation flap (Fig. 5). The latter flap has been little used by the author. The swinging-rotation flap is rendered mobile by a counterincision, *ab*, the "tail" of the rotation flap (Figs. 4,*A* and 4,*B*). After the flap has been shifted, a secondary defect is produced, which is closed by direct approximation. Large secondary defects may require skin-grafting. The line of suture of the secondary defect tends to form

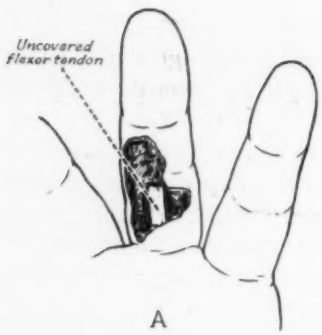


FIG. 1-A

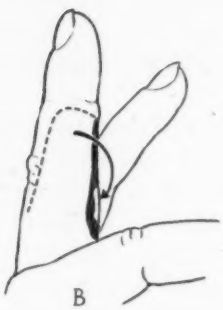
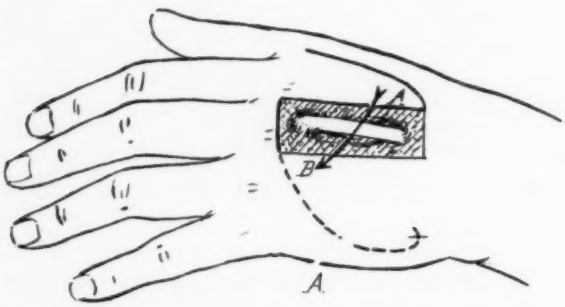


FIG. 1-B

FIG. 1-C



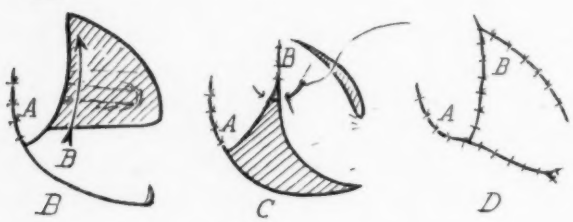


FIG. 2

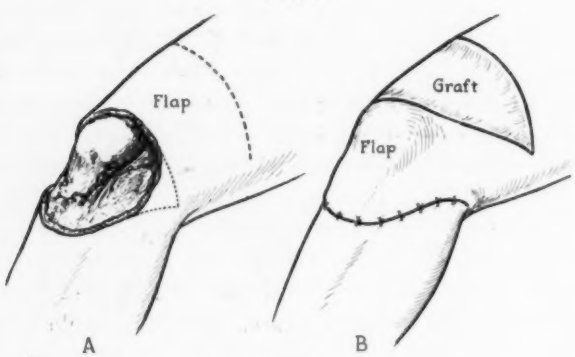


FIG. 3

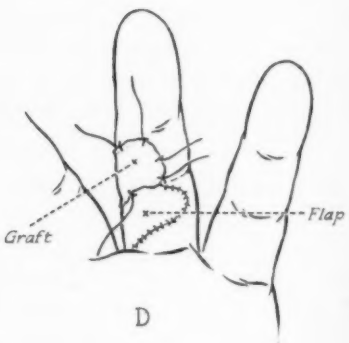


FIG. 1-D

Figs. 1-A, 1-B, 1-C, and 1-D: Transposed flap. Example of useful application of a flap, transposed from the lateral aspect of the finger, to cover an exposed flexor tendon. The raw area, resulting from the transfer of the flap, is covered by a free skin graft of intermediate thickness.

Fig. 2: Transposed flaps. Two flaps, *A* and *B*, are transposed over a defect which left an extensor tendon uncovered. Direct closure is possible, after wide undermining of the surrounding skin, because the skin of the area is abundant and loose.

Fig. 3: Bipedicle transposed flap. A good application of a bipedicle transposed flap to cover a patella denuded of periosteum. In *B*, the donor area has been skin-grafted.

a 90-degree angle with the line of tension of the flap. In this manner added tension on the latter is avoided. The combined use of transposed and rotation flaps has permitted a wide scope of applications in the repair of defects of moderate size.

Limitations of Local Flaps

The utilization of local flaps is limited by the size of the defect and by the type of tissue which surrounds the defect. Local flaps of large size necessitate the shifting of tissue situated around the circumference of the extremity and thus produce a circular scar,

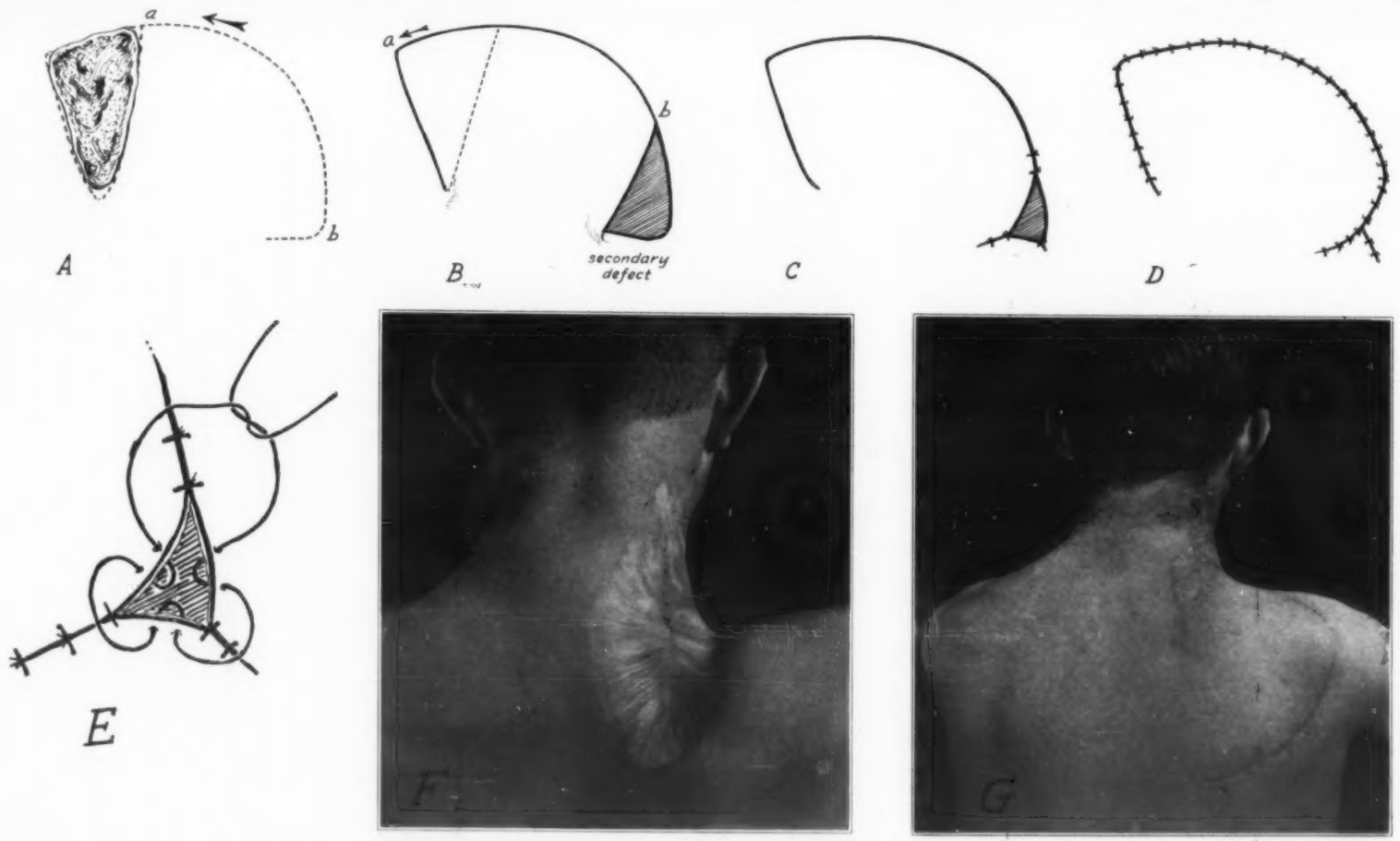


FIG. 4

Swinging-rotation flap. *A*, *B*, *C*, *D*, and *E* are diagrammatic representations of a swinging-rotation flap. The "tail" of the rotation flap, *b*, facilitates the movement of the flap. The secondary defect is closed at a right angle with the line of tension of the flap (*C*, *D*, and *E*). *F* and *G* show application of a swinging-rotation flap to cover a suprascapular defect.

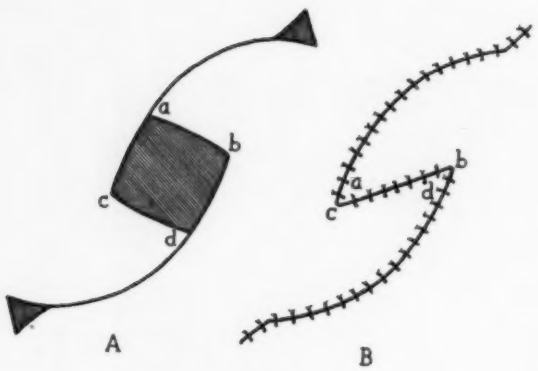


FIG. 5

Advancement-rotation flap. The excision of the triangles at the base of the rotation flaps facilitates their advancement and rotation.

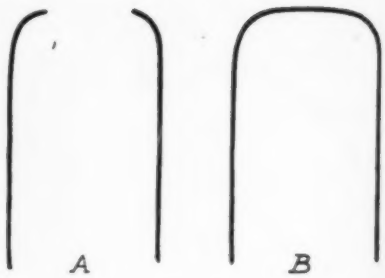


FIG. 6

Delayed flap. In a first stage, *A*, the flap is raised from the underlying fascia between two lateral incisions outlining the angles of the flap. In a second stage, *B*, the whole flap is raised and transplanted.

obstructing the lymphatic and venous return, at least temporarily. When the skin situated around the defect is loosely bound to the underlying fascia, it is possible to transpose or to rotate adjacent flaps in an efficient manner. This procedure is often possible in the upper extremity. In the hand, local flaps are satisfactory on the dorsum, but often fail in the palm, where the skin is thickened by a heavy layer of corneum and rendered tight and resistant by fibrous septa, which bind it to the deep palmar fascia. In the lower leg, the ankle, or the foot, local flaps must be executed with greater prudence, often after a preliminary delay, because the skin is less elastic than in the upper extremity. When placed under any degree of tension, such flaps tend to become necrosed by diminution of the blood supply. This danger is the greatest when dealing with the skin of the sole of the foot, which is functionally differentiated skin. In such areas, experience has proved that flaps from a distance are indicated in all but small defects.

FLAPS FROM A DISTANCE

Flaps from a distance may be defined as distinct from local flaps by the fact that they are carried over an area of normal skin, before reaching the defect. Distant flaps may be taken from a donor site, situated not far from the recipient area; they may be carried from the donor site to the recipient area on the forearm, wrist, or hand; or they may be migrated by reimplanting one detached end of the flap into a position closer to the defect.

Types of Flaps from a Distance

Flaps from a distance may be called *direct* when the flap, after being raised, is transferred immediately to the recipient site, and *indirect*, when it is carried or migrated to the recipient area. Such flaps are *open*, presenting a raw area on the undersurface, or *closed* when this raw area is eliminated by one of three methods:

1. By tubing the flap (Gillies);
2. By skin-grafting the undersurface of the flap;
3. By covering this undersurface with another skin flap.

Open direct flaps may be transplanted *undelayed*, when, after being raised, they are sutured at once into the defect. However, the vitality of such flaps may be doubtful:

1. When the length of the flap exceeds one and one-half times its width;
2. When the flap must be twisted or kinked to reach its destination;
3. When the flap must be cut counterwise to the direction of the blood supply, or when it must cross the mid-line. Across the mid-line of the trunk, the blood vessels present fewer and smaller anastomoses than they have on each side of the mid-line.

TABLE I

COMPARATIVE APPROXIMATE LENGTH OF TIME REQUIRED BY DIFFERENT METHODS OF SKIN REPLACEMENT

Type of Flap	Days Required
Local flap	10
Free skin graft	10
Direct pedicle flap	24
Direct open "delayed" flap	38
Closed carried flap	32 to 52
Abdominal tubed pedicle flap, carried on the wrist	53 to 73

Under these conditions, if the viability of the flap is questionable, it should be *delayed* by a preliminary section of the vascular connections of the flap on the sides of the flap and beneath it. This procedure causes an increase in the size and number of the longitudinal vessels in the flap [4]. In performing a delayed flap, it is preferable to avoid raising the whole flap; instead, two longitudinal incisions, curved to outline the corners of the flap, are made, and the flap is raised from the fascia between these two incisions (Fig. 6). In this manner, there is no postponement of the transfer because of an ischaemic necrosis of the end of the flap. The transfer of a flap, after delay, can usually be accomplished in ten to fourteen days. There does not appear to be a contra-indication to postponing the transfer of the flap for a number of weeks after the delay, as the lateral blood vessels do not grow through the scar until after the latter has become softened. It is felt that, if the flap is cut and completely raised, as is frequently practised, and if necrosis does not ensue, this preliminary delay of the flap is an unnecessary and superfluous procedure. It will be objected that the angle of transfer of the flap may be such that it will not survive unless a delayed flap is used. If such an angle is necessary, it is probable that the flap was badly planned. It is interesting to note that in the author's series of 379 flaps from a distance, only eight were delayed flaps.

A widely known delayed flap is Gillies's tubed pedicle flap. The advantage of the tubed flap is the relatively long time required for its construction and transfer (Table I). The tubed pedicle flap will remain the method of choice for the transfer of abdominal flaps by migration to the lower extremity in aged patients, to whom a direct cross-leg flap causes too great a discomfort. When, for aesthetic reasons, a cross-leg flap is contra-indicated in female patients, the tubed pedicle may be transferred by way of the wrist.

Because of their greater speed of execution, direct flaps have been employed whenever possible in the present series of patients, who were nearly all war casualties and young, healthy, male patients. Before any flap is planned, it is essential to obtain the exact measurements of the defect to be repaired.

The Apparent Defect and the True Defect

The true defect is not represented by the size of a cutaneous scar, because contraction of the wound occurs in the course of wound healing. Furthermore, the area of the subcutaneous scar always exceeds that of the cutaneous scar, because the skin has been drawn over the wound during the process of healing. In consequence, a scarred surface should be excised widely, so as to remove all of the subcutaneous scar tissue. Scar contraction is greater when the skin of the area is loosely bound down to the underlying structures. It is marked in the vicinity of joints, because the latter have become flexed or extended, thus diminishing the size of the healing wound. The healed area thus constitutes only the apparent defect, which is smaller than the true defect. The size of the latter may be determined by a procedure which we may call "mapping".

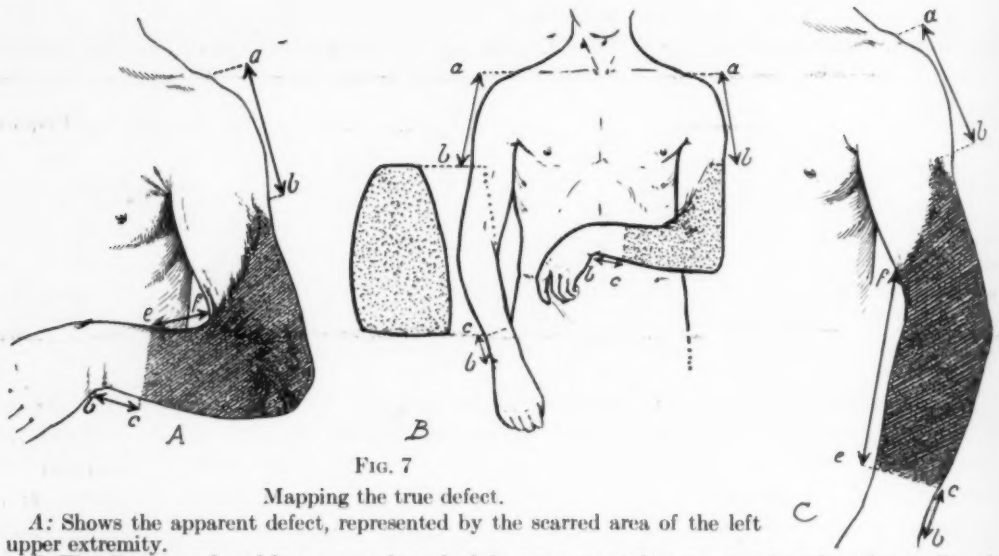


FIG. 7

Mapping the true defect.

A: Shows the apparent defect, represented by the scarred area of the left upper extremity.

B: The distances *ab* and *bc*, measured on the left upper extremity, are transferred to the unaffected right upper extremity. The true homologous defect can be mapped out on the right upper extremity.

C: The true defect becomes apparent after the excision of all scar tissue. Compare the size of the shaded area in *A* to that in *C*.

Mapping the Defect

Accurate mapping of the true defect can be done when the opposite limb is unaffected (Fig. 7). The procedure of mapping the defect of a scar contracture of the arm and forearm would be carried out as follows:

The upper extremities are compared; on the affected limb, bony landmarks (such as the acromion and the radial styloid) are marked on the skin with ink (Fig. 7,*B*). The distance *ab* from the superior limit of the scarred area to the acromion is noted, and an equivalent distance, *ab*, from the acromion is marked on the normal arm.

After the distance from the lower border of the defect to the radial styloid, *bc*, has been noted, the distance *bc* is measured on the normal arm (Fig. 7,*B*); the upper and lower limits of the true defect are thus obtained. The distance between the medial and lateral limits of the scarred area is obtained by passing the measuring tape around the unscarred portion of the arm at the point where the scar appears the widest; this measurement is noted on the normal arm, and thus is obtained the width of the true defect. By repeating these manoeuvres, each corresponding point of the true defect can be obtained; these points are then joined by a line, limiting the true defect which will be obtained after the complete excision of the scarred skin and underlying scar tissue (Fig. 7,*C*). After the extent of the defect has been determined by mapping, the flap should be carefully planned and designed before the operation is attempted.

The Planning of the Flap

In planning a skin flap, the following points should be observed:

1. *The flap operation should cause as little discomfort as possible to the patient.*

This condition is particularly important in older patients. It is also an insurance in favor of adequate immobilization during the healing of the flap, as a patient who is uncomfortable will become restless and endeavor to modify his position. In the repair of defects of the finger tips, flaps from the thenar eminence to the finger tips, from one finger to its neighbor (cross-finger flaps), from the opposite arm to the finger, and from the opposite forearm to the finger cause little discomfort.

In the repair of defects of the hand, flaps from the opposite forearm and arm have been used often in preference to thicker abdominal flaps for the repair of the palm. The use of a flap taken from the opposite upper extremity, chosen for reasons described later, necessitates the immobilization of both upper extremities in the cross-arm position. Such positions are inconvenient, not only on account of the discomfort, but also because of the temporary loss of function of the arms.

The forearm and arm can be covered generally by abdominal or chest flaps. The position of the upper extremity against the trunk which is the least uncomfortable for abdominal and chest-flap transfers is the following: The hand is placed over the opposite upper quadrant of the abdomen; the forearm, elbow region, and arm can then be held firmly immobilized against the trunk by means of a many-tailed abdominal binder. For the lower extremity, the easiest position of transfer is the cross-leg method, which is not unduly uncomfortable, provided that hyperflexion or hyperextension of the knee and external rotation at the hip joint are avoided and that firm immobilization in plaster is assured. The discomfort caused by a cross-leg flap is less than that caused by the transfer of a tubed pedicle flap carried on the wrist to the lower extremity.

2. *The transfer of the flap should be accomplished as quickly as possible.*

Rapid repair will accelerate the patient's return to normal activity and work, and the date of any secondary operation is advanced. Direct flaps are the most rapidly executed.

3. *The skin flap should be removed from a suitable donor area.*

The raising of a skin flap creates a secondary defect; therefore, the donor area of a flap should be chosen with care, particularly in female patients.

Whenever possible one should choose a region, such as the abdomen, in which a secondary defect may be closed by direct suture.

It is essential to select a region where a secondary defect may be repaired satisfactorily by skin-grafting. A flap should not be removed from over bone which is immediately subcutaneous, because the full thickness of the skin is needed to protect the bone.

The loss of tissue in the donor area should be less important than the repair of the primary defect. Thus an abdominal defect, created by the transfer of a flap to the hand, is of little importance if it has made possible the covering of denuded tendons.

The best match of tissue texture and thickness is achieved when the skin of a homologous region can be utilized,—for example, a cross-leg flap.

The Design of the Flap

After the extent of the true defect has been determined and the flap to be utilized has been planned, an accurate design of the future flap may be obtained by the method described by Gillies. The recipient and donor areas are brought into the positions they will assume during the transfer of the flap. A pattern is cut to shape, and fitted as though the operation of flap transfer had been finished (Fig. 8,*D*). The pattern is held to the donor area while the recipient limb is displaced and it is then spread over the donor area (Fig. 8,*E*). Its exact position is noted, and the patient's name is marked on the pattern, which is sterilized in readiness for the operation.

The following points should be observed in designing a flap:

1. The length of the flap should not exceed one and one-half times its width.

2. The angle at which the flap leaves the donor area should be as wide as possible, so as to avoid a kink detrimental to its blood supply.

3. Tension on the flap should be avoided, not only by employing a flap of adequate dimensions, but by the careful choice of the best angle for the line of attachment of the pedicle flap.

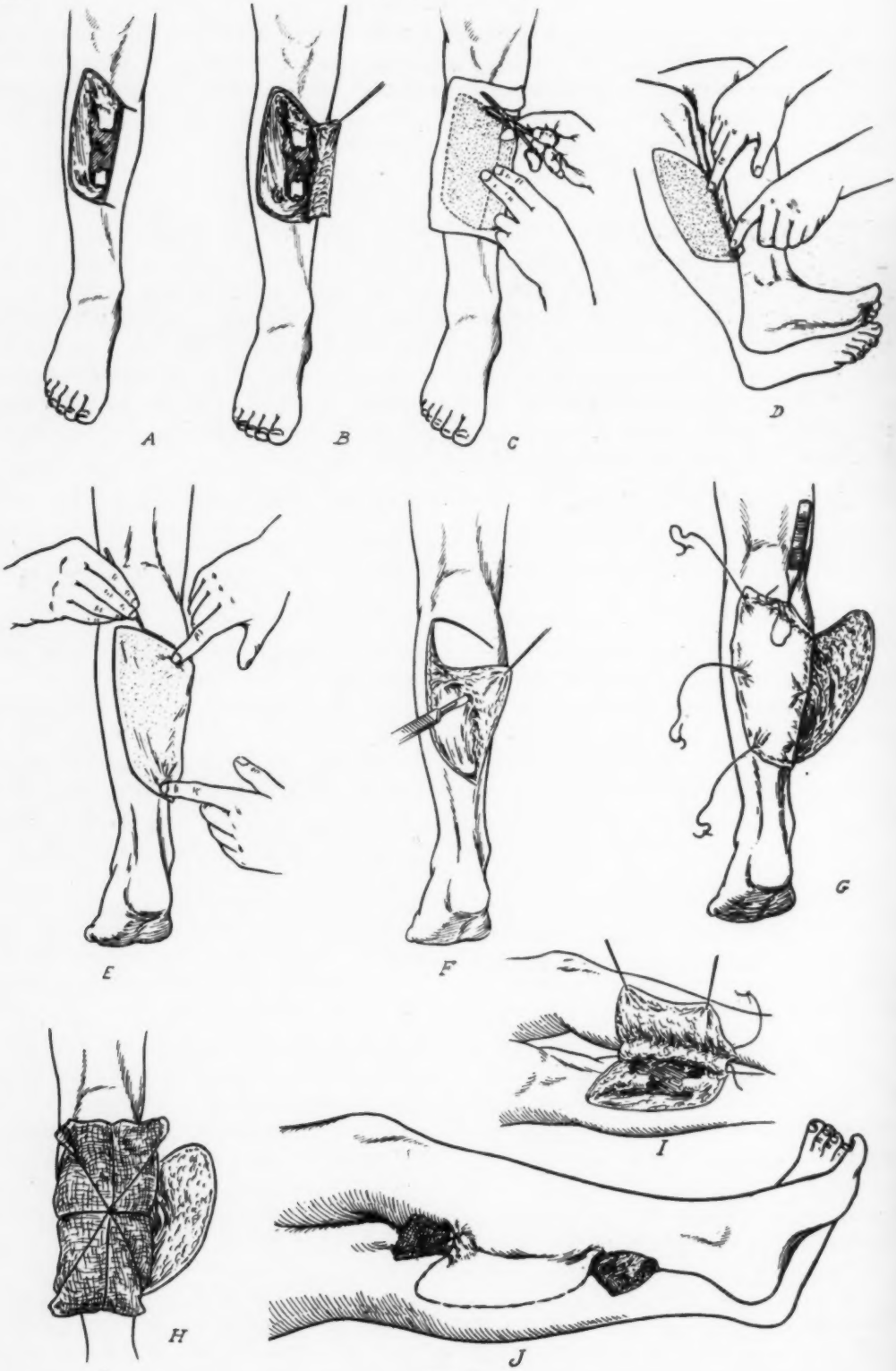


FIG. 8

A typical cross-leg flap operation.

A: Appearance of defect after excision of all scarred or infected tissue.
B: The hinge flap is raised.

(*Continued on page 173*)

FIG. 8 (*Continued*)

C: The pattern of the defect is made.
D: The pattern is placed as though the flap transfer had been completed.
E: The pattern is placed over the donor area and is outlined with ink.
F: The flap is raised from the deep fascia.
G: An intermediate-thickness skin graft is sutured over the defect produced by raising the flap.
H: Tied-in pressure dressing over the skin graft.
I: The hinge flap is sutured to the base of the cross-leg flap.
J: The cross-leg flap in place. Intradermal sutures avoid the need for skin sutures.

FIG. 9-A

FIG. 9-B

Pedicle-flap covering of the saucerized bone cavity.

Fig. 9-A: Shows saucerized granulating cavity of the distal portion of the tibia.

Fig. 9-B: The cavity has been lined with a thin skin graft, applied on a mold of dental compound. (This skin graft over bone is unstable and the author feels that this stage is unnecessary.)

Fig. 9-C: The cavity has been covered by a cross-leg pedicle skin flap after the removal of the skin graft.

FIG. 9-C

Preparation of Wound for Flap Transfer

Often a flap is applied to replace an unstable scar, covering bone or incorporating within its mass, tendons, nerves, or joints. In an increasing number of patients, the early application of a flap to an open wound with loss of tissue is followed by success, if suitable preparation of the wound is carried out.

In the early part of the War, in the cases of this series, all wounds of compound fractures with loss of soft tissue were treated by the closed plaster method until consolidation of the fracture. The soft-tissue defect was repaired early by free skin-grafting, but necessary flap repairs were done later[2]. In many cases, consolidation did not occur; and in some, considerable necrosis and sequestration of the uncovered bone took place. All in all, the treatment of such cases was greatly prolonged. Some wounds and saucerized bone cavities were even skin-grafted so as to obtain complete healing before a flap was contemplated (Figs. 9-A, 9-B, and 9-C). Wounds with superficial-tissue loss presented added tissue loss by ischaemic necrosis of the exposed tissue and by infection and suppuration; prolonged exudation and suppuration caused nutritional disturbances due to protein loss.

The great advantage of obtaining a rapid covering of such wounds gradually led to the earlier use of flaps over open wounds. However, careful consideration should be given each wound before operation. Indications for postponing the flap operation are redness and oedema of the wound margins, elevation of temperature, and profuse discharge. The presence of a hemolytic streptococcus in the wound is considered as a contra-indication to

operation. Penicillin therapy is instituted, and moist dressings are applied, with pressure over the wound and with a pressure bandage over the portion of the extremity distal to the wound. The immobilized extremity is elevated.

Windows in the plaster were found to lead to wound oedema; instead, the plaster was bivalved to permit changes of dressings, if these were required. Closure of a wound by a flap should not be done when the wound is discharging pus, as this usually indicates the presence of infected and necrotic tissue in the depth of the wound. Such a wound can be closed by a flap only if complete excision of all devitalized tissue can be done, if the wound presents no recesses, and if the wound can be laid flat in such a manner that the flap can be applied without leaving any dead space under it.

In dealing with compound fractures discharging pus, immobilization in plaster is necessary. In compound fractures of the leg, one should be particularly careful to obtain control of the suppuration before covering the wound with a flap, as there is no adequate posterior drainage route for the shaft of the tibia. Before a plaster is applied, all necrotic tissue and loose bone fragments should be removed, recesses in the wound should be opened, and the wound should be packed open with gauze. When bone is devitalized through exposure, it should be removed surgically before the remaining bone is covered by a flap, in order to prevent burying dead bone under the flap.

All flap operations over open infected wounds were considered to justify a protective penicillin "cover" which was given postoperatively until the likelihood of invasive infection was passed.

TECHNIQUE OF THE TRANSFER OF FLAPS FROM A DISTANCE

Certain points of technique are common to all flap transfers; others are specific to certain particular flaps.

I. *Technique Common to All Flaps*

A. *Hemostasis*

A flap of the suitable size and shape having been cut, and the recipient area having been completely freed of all scar tissue, it is necessary to ensure that all bleeding vessels have been ligated, so as to avoid a hematoma under the flap. Silk, of the finest size, appears to be well tolerated beneath a skin graft. It is tied with the needle holder.

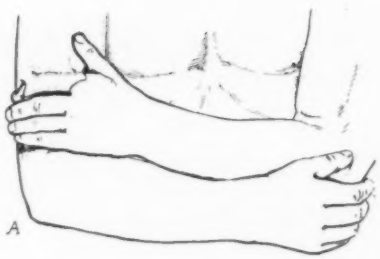
B. *Suture*

Careful suture of the edges of the flap to the edges of the surrounding skin is essential to achieve good primary healing. Usually the flap is thicker than the surrounding skin and subcutaneous tissue; and thinning of the flap by resecting some of its fat is hazardous, because it endangers the blood supply to the flap. However, accurate apposition can be obtained by placing numerous U-shaped intradermal sutures of white silk or cotton so that the skin edges are approximated, even without placing skin sutures. These intradermal sutures are of special value when immobilization in plaster is carried out, particularly for cross-leg flaps. They avoid stitch abscesses or even stitch marks, caused by skin sutures left under a plaster cast. Epithelial apposition may be completed by placing a few sutures of the finest material (size 6–0 silk). Such fine sutures, placed without undue tension, may be kept in place for two or three weeks without causing inflammation.

C. *Elimination of the Raw Area. Skin-Grafting the Donor Area*

One should endeavor to make the procedure of a flap transfer a closed operation by eliminating raw areas, produced by the raising of the flap, in the following manner:

1. By bringing the recipient area as close as possible to the donor area along the line of attachment of the flap.



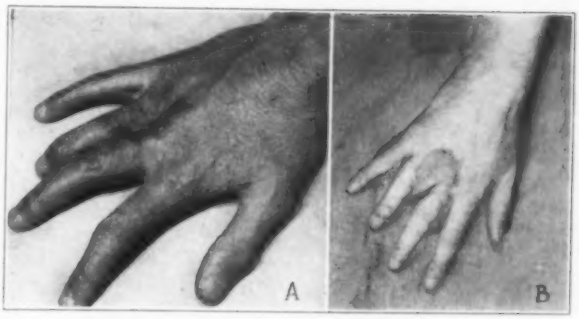


FIG. 10

FIG. 11

Fig. 10: Positions of transfer for cross-arm flaps.
A: Flap repair of finger.
B: Bipedicle flap repair of finger.

Fig. 11: *A:* Syndactylism with adhesions of extensor tendons in the scar and synostosis between the third and fourth metacarpal bones.
B: Appearance after the restoration of the interdigital space.
C: The cross-arm flap procedure was used in this case which required a skin flap, rather than a free skin graft.

FIG. 12

Fig. 12: Cross-arm flap. A flap taken from the opposite forearm furnishes soft and pliable skin for the resurfacing of the palm of the hand.

2. By skin-grafting immediately or closing by direct approximation the raw area, produced by the raising of the flap. A split-thickness skin graft, held to the edges of the defect by a continuous running lock stitch, and maintained by a pressure dressing tied into the defect, gives a satisfactory repair (Figs. 8,*G* and *H*). When moderate-sized flaps from the abdomen are employed, one can close the defect by carefully suturing the wound after extensive undermining. A continuous intradermal suture with a stainless-steel wire (gauge 35) closes the wound with an even distribution of tension. Since the suture is usually well tolerated, it may be left *in situ* from ten to fifteen days. It is preferable, however, to skin-graft the defect, rather than to attempt to close it with undue tension.

3. By employing the hinge flap.

As stated previously, the portion of the flap situated between the recipient area and the attachment of the flap should be as short as possible. However, in order to eliminate completely the raw area under the flap, it has been found advantageous to make a hinge

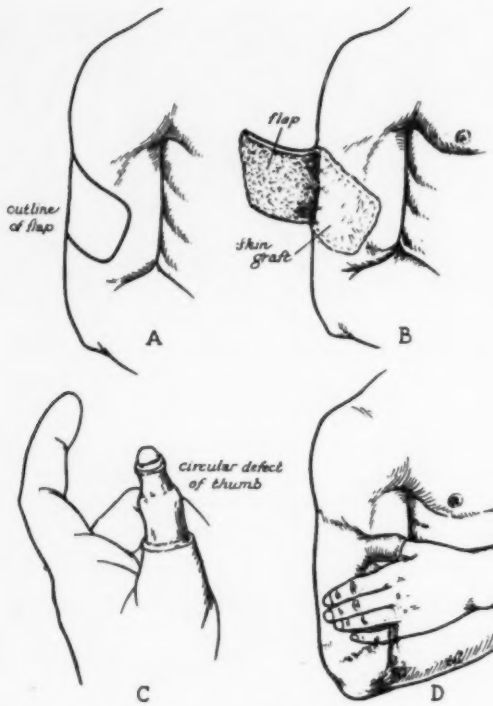


FIG. 13

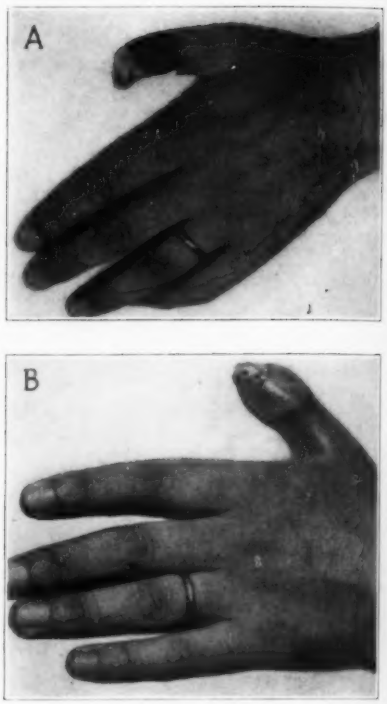


FIG. 14

Fig. 13: Covering of a circular defect of the thumb.
A: Outline of direct flap on anterior lateral aspect of the right arm.
B: The flap is raised; an immediate skin-graft covering is provided to the raw area left by the raising of the flap.
C: Appearance of circular defect of the left thumb after excision of the scar tissue.
D: The brachial flap has been applied to the thumb defect.

Fig. 14: *A:* Circular loss of skin of the left thumb, as a result of crushing.
B: Replacement of skin covering, as shown in Fig. 13.

with normal skin on the side of the defect opposite the attachment of the pedicle flap (Fig. 8,*B*). This hinge flap is sutured to the undersurface of the main flap, thus closing it completely along its base. The hinge flap has been shown to present the following four main advantages:

a: The avoidance of infection and suppuration on the undersurface of the flap, particularly when the defect presents exposed tendons, which are especially susceptible to infection.

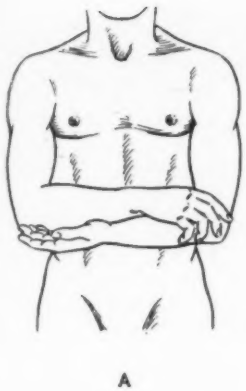
b: The avoidance of inflammation after the section of the pedicle along the line of secondary suture, because the area has been kept rigorously closed by the hinge flap.

c: The elimination of tension, and thus of inflammation and of delayed healing, along the line of suture of the sectioned pedicle. It was noted repeatedly that, when there was an excess of tissue, such as is provided by the hinge flap, thus eliminating tension, healing occurred satisfactorily. Slow healing due to tension along the line of section of the pedicle was seen particularly in flap repairs of the foot. The adoption of the hinge flap greatly accelerated the healing time of such wounds.

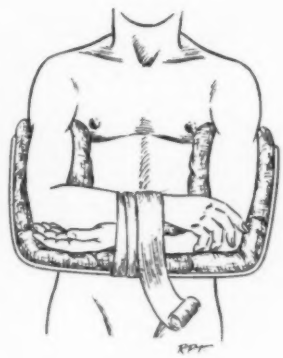
d: The hinge flap, which is made with healthy tissue, helps to give the main flap strong vascular connections, particularly when the latter is applied to a poorly vascularized area.

D. *The Length of Time Before the Separation of the Flap*

Under ordinary circumstances, flaps may be separated around the fourteenth day.

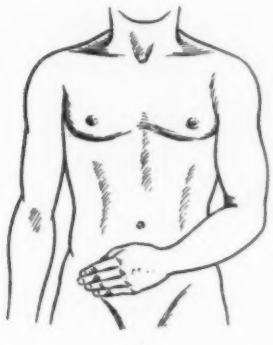


A



B

FIG. 15



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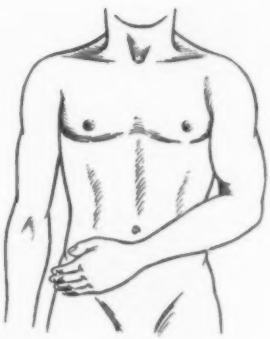

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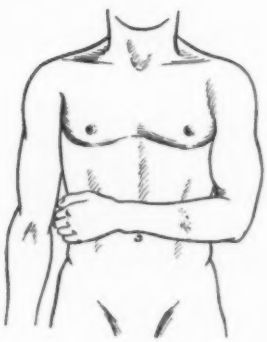

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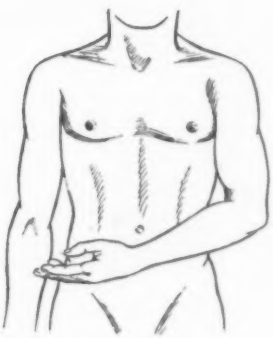

D

FIG. 16

Fig. 15: Splinting in cross-arm flaps.
A: Typical position for the repair of the palm by a flap from the opposite forearm.
B: U-shaped splint, made with padded wire, immobilizing the upper extremities.

Fig. 16: Various positions for the transfer of abdominal flaps to the hand and forearm.

When conditions are unfavorable for the normal revascularization of the flap, as when the flap is placed over denuded bone, about twenty-one days should elapse before the separation of the flap. When the whole of the defect cannot be covered in one stage, the portion of the flap applied in the first stage must serve as the base for vascular supply of the whole flap in the second stage. It is prudent to wait twenty-one days before sectioning the flap, so as to permit the newly transplanted flap to acquire strong vascular connections.

II. *Technique Particular to Certain Flaps*

A. *Flaps to the Upper Extremity*

Flaps to the upper extremity are of two main varieties: flaps transferred from one upper extremity to the other, or cross-arm flaps, and flaps transferred from the trunk to the upper extremity. One or the other of these flaps was used in the repair of the various segments of the upper extremity.

1. *Flap Repairs of the Hand and Forearm:*

In repairs of the fingers, the interdigital spaces, and the palm of the hand, the author has used cross-arm flaps, taken from the homologous upper extremity. In spite of the immobilization of both arms, this procedure is preferred in many cases, because the skin transferred is thinner, softer, and more pliable than abdominal skin. Figures 10, 11, 12, 13, and 14 show the various positions of transfer of such cross-arm flaps. In cross-arm flaps, a

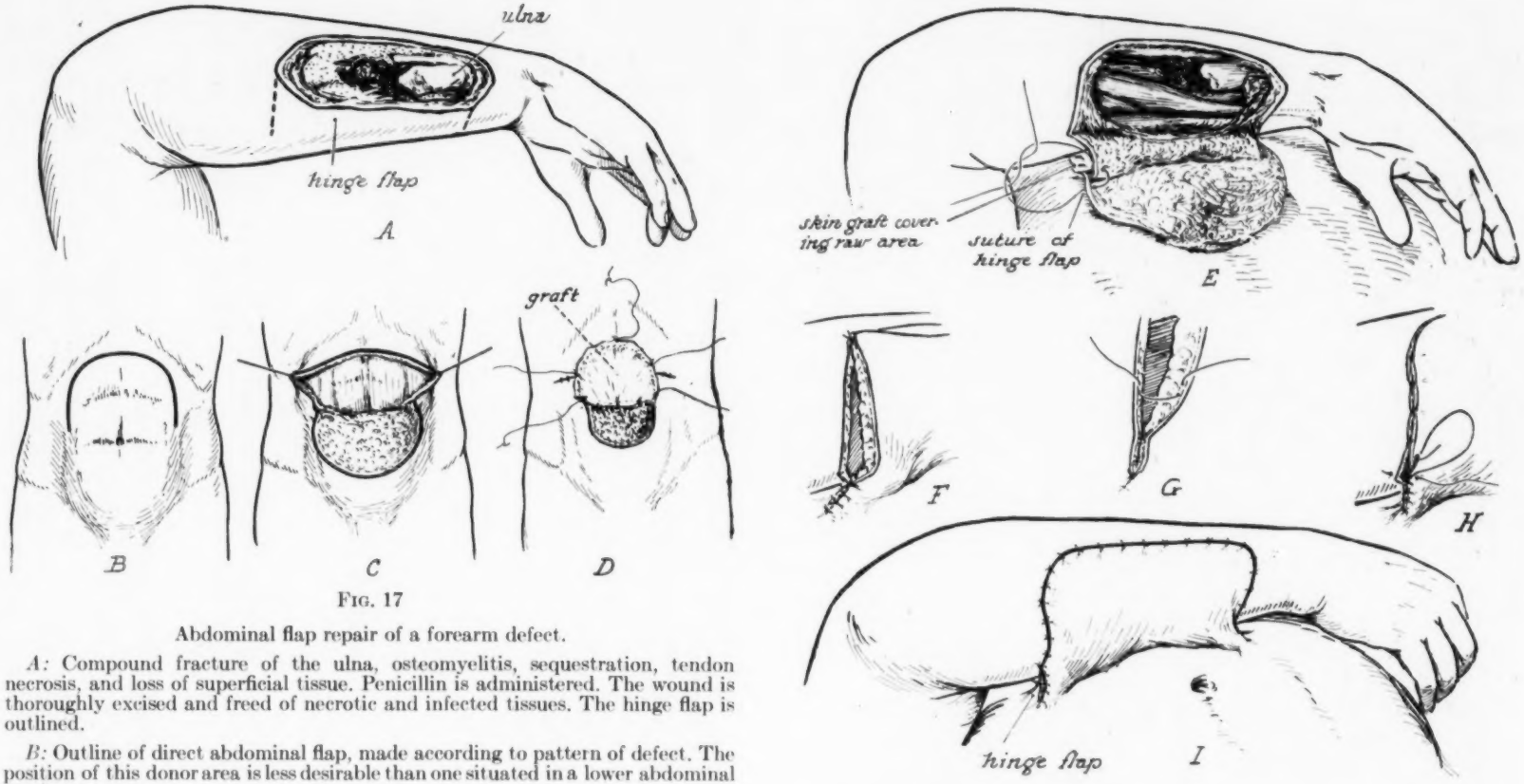

FIG. 17

Abdominal flap repair of a forearm defect.

A: Compound fracture of the ulna, osteomyelitis, sequestration, tendon necrosis, and loss of superficial tissue. Penicillin is administered. The wound is thoroughly excised and freed of necrotic and infected tissues. The hinge flap is outlined.

B: Outline of direct abdominal flap, made according to pattern of defect. The position of this donor area is less desirable than one situated in a lower abdominal quadrant.

C: The direct flap is raised. The lateral ends of the defect will be sutured, so as to diminish the area to be skin-grafted.

D: The skin-graft dressing has been sutured over the raw area. A tied-in pressure dressing will be applied over the graft.

E: The hinge flap is sutured to the base of the abdominal flap.

F, G, H, and *I:* Phases in the dermal and cutaneous suturing of the abdominal flap to the edges of the antebrachial defect.

FIG. 18

A: Suppurating infected wound of the forearm, surrounded by area of scar tissue.
B: After transfer of direct abdominal flap, according to the technique described in Fig. 17.

U-shaped splint provides firm immobilization of the extremities (Fig. 15). Abdominal flaps have been used for the repair of defects of the dorsum of the hand, of the forearm, and of the elbow region (Fig. 16). The upper extremity is held against the trunk and immobilized during the transfer by adhesive tape and many-tailed bandages. Relaxation of the abdominal wall is obtained by elevating the patient's head and lower extremities. This position permits, in many cases, the direct suture of the abdominal defect. An abdominal flap may have the base of its pedicle above or below. Theoretically, a flap taken from the upper part of the abdomen should have its pedicle based above, so as to receive a blood supply from the branches of the internal mammary artery; a flap taken in the lower part of the abdomen should have its pedicle based inferiorly, so as to receive the branches of the deep epigastric artery. Practically speaking, the position of the base is determined by the site to be repaired. In defects of the dorsum of the hand and of the dorsal aspect and radial border of the forearm, an abdominal flap based above is used. In repairs of the volar aspect of the forearm and its ulnar border, a flap based inferiorly is applied (Figs. 17 and

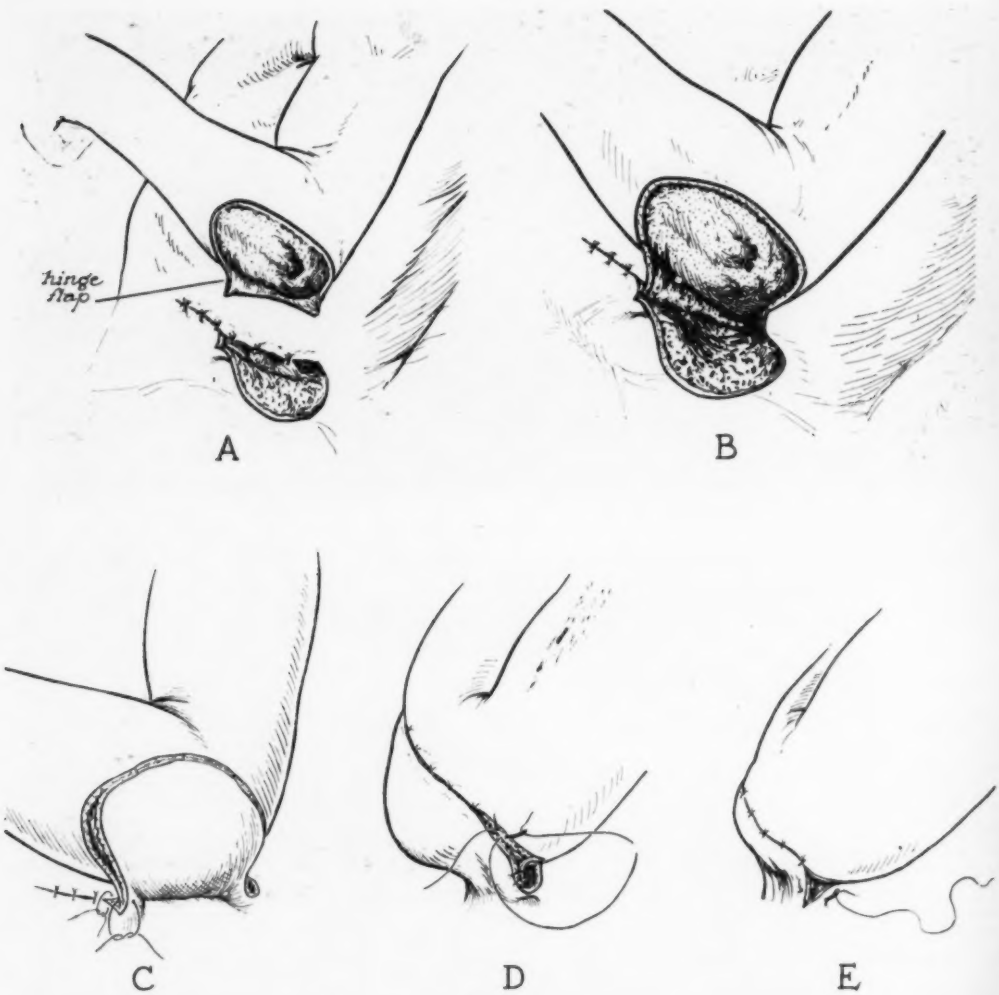

FIG. 19

Fig. 19: Direct abdominal-flap repair of the elbow.

A: The abdominal flap has been raised and the abdominal defect has been closed. The flap is ready to be applied to the elbow defect.

B: Suture of the hinge flap.

C, *D*, and *E:* Suture of the flap.

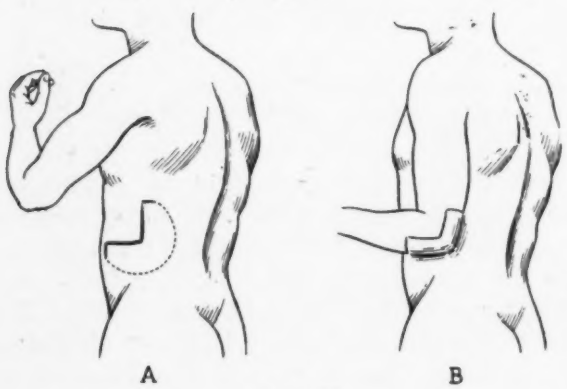

FIG. 20

Fig. 20: Abdominal flap repair of the elbow.

A: Incisions at right angles delimit the flap, destined to cover the elbow region, when the joint is ankylosed in a 90-degree position.

B: The elbow is placed in a pocket, created by undermining the abdominal skin.

18). Abdominal flaps to the hand and forearm are often thick and usually necessitate subsequent thinning. A few weeks after the flap has healed, one half of the flap is raised, and a layer of fat is excised. The other half of the flap is left attached, so as to ensure the vascularization of the flap. A few weeks later, the same procedure is carried out with this latter half of the flap, which is thinned in the same manner.

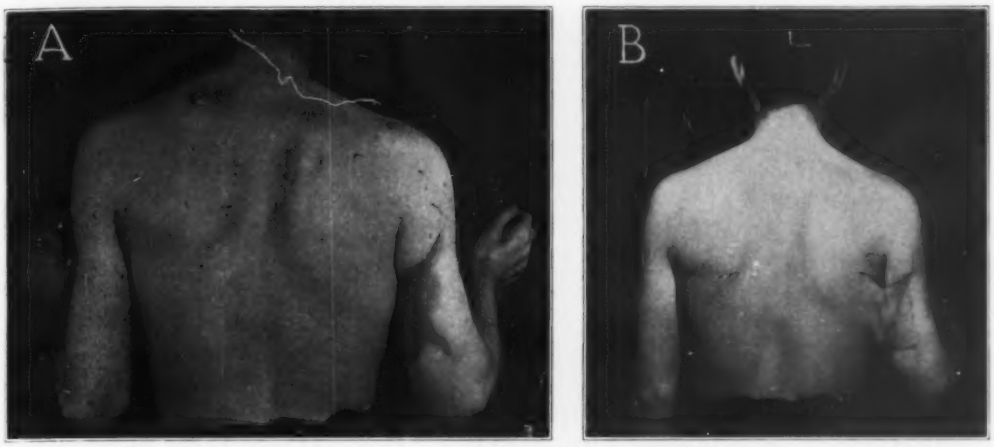

Fig. 21: A thoracobrachial flap.

A: Defect of the posterior medial aspect of the right arm. The patient presents an ulnar-nerve paralysis.

B: The thoracobrachial flap during transfer.

C: Satisfactory resurfacing of the arm. The ulnar nerve was sutured later.

FIG. 21

Fig. 22: *A:* Compound fracture of the elbow. A resection of the joint is necessary. Adequate soft-tissue covering must be provided.

B: A direct abdominal flap has been applied after complete excision of the scarred and infected tissues. Note the generous size of the flap and also the position of the upper extremity against the trunk.

C: The flap after healing. The donor area on the abdomen has been partly closed by direct approximation. The remainder of the defect has been skin-grafted.

FIG. 22

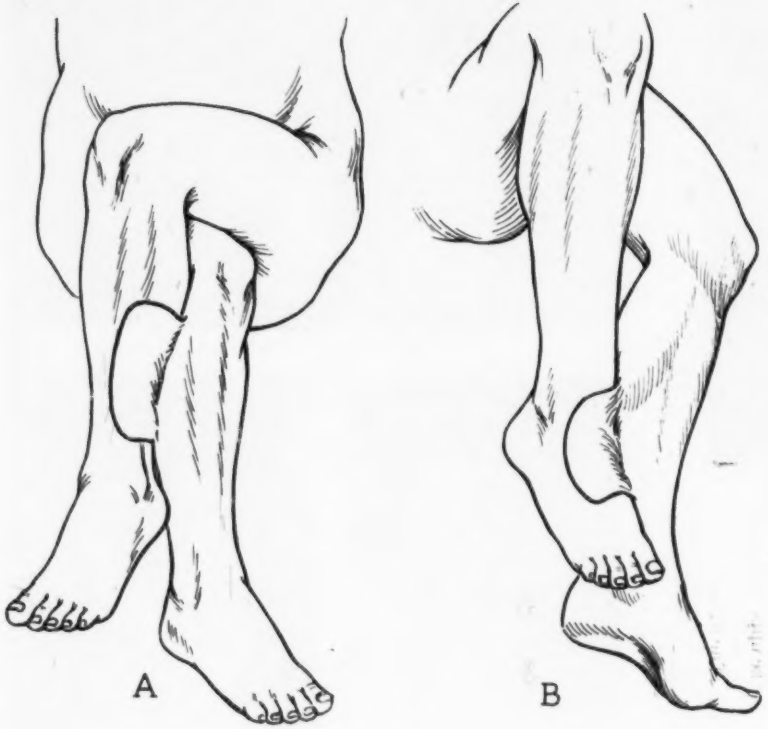

FIG. 23

Fig. 23: Positions for flap transfer from one lower extremity to the other.
A: The legs are crossed.
B: The legs are parallel.

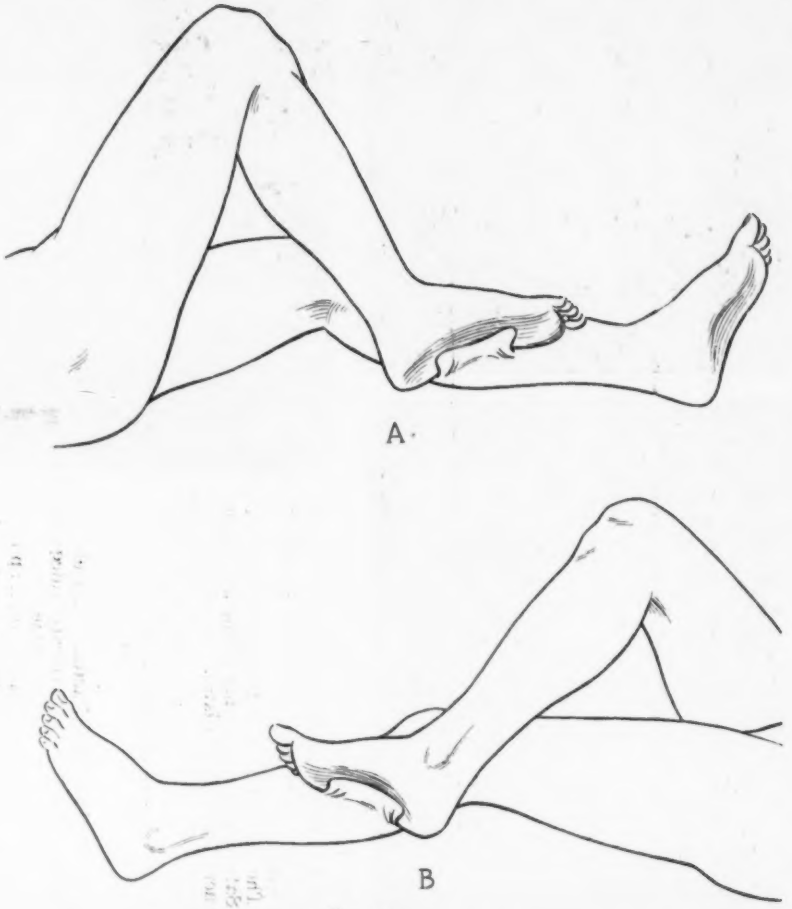

FIG. 24

Fig. 24: Positions of transfer for flap repairs of the sole of the foot.
A: Repair of the medial aspect of the sole.
B: Repair of the lateral aspect of the sole.

FIG. 25

Suspension-elevation of the lower extremities after a cross-leg flap. This position favors venous and lymphatic drainage and simplifies the nursing care of the patient.

FIG. 26-A

FIG. 26-B

Fig. 26-A: Flap repair of the heel. Shows position of transfer of the flap for repair of the heel.
Fig. 26-B: Similar position for flap repair of the posterior aspect of the leg.

2. *Flap Repairs of the Elbow:*

For the elbow region, a flap raised just above the iliac crest is employed (Fig. 19). In the lower abdomen, the superficial fascia contains elastic tissue in sufficient abundance to comprise a separate stratum, the fascia of Scarpa. Flaps taken from this region present a natural elasticity and are particularly suitable as a covering for a mobile region, such as the elbow. In repairing the medial surface of the elbow, a flap with a pedicle based above is used. When the lateral surface needs a flap repair, the base of the flap is placed inferiorly (Fig. 22). When repair is needed on both the lateral and medial aspects of the elbow, a flap based inferiorly is used to cover the lateral surface, and the olecranon is buried in a

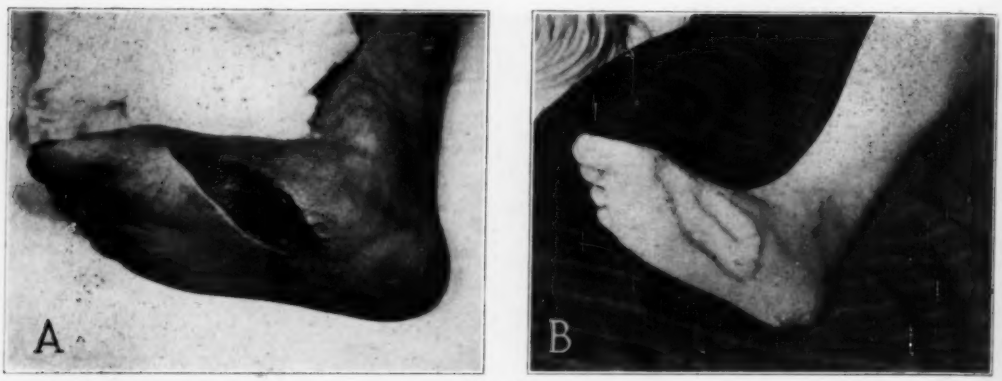

FIG. 27

Flap repair of the sole of the foot. *A:* Wound with skin loss of the medial portion of the sole. *B:* Repair by a flap from the opposite leg, as illustrated in Fig. 24,*A*.

pocket, produced by undermining the base of the flap (Fig. 20). The upper edge of the abdominal skin defect is sutured to the edge of the defect on the medial aspect of the elbow. In a second-stage operation, two or three weeks later, another flap, based upon the portion already inserted upon the lateral aspect of the elbow, covers the medial aspect.

3. *Flap Repairs of the Arm:*

Thoracobrachial flaps present relatively little discomfort during transfer. These flaps are based posteriorly for the repair of the posterior aspect of the arm (Fig. 21), and anteriorly for the anterior aspect of the arm.

B. *Flaps to the Lower Extremity*

Cross-leg flaps are usually performed to procure a skin covering to the bones of the leg or of the foot. The donor site for the flap is usually the posterior or the posteromedial aspect of the opposite leg, various positions of transfer

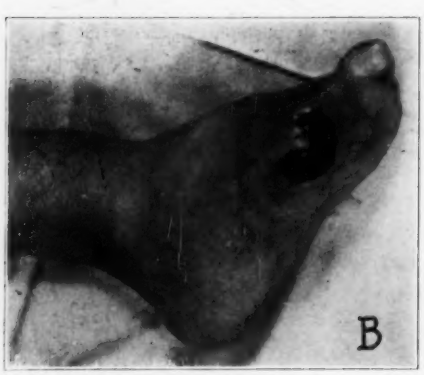

FIG. 28

Flap repair of the anterior region of the foot. *A:* Position of transfer of the flap. *B:* Aspect of the foot before the excision of an indolent ulcer and scar tissue. *C:* Skin replacement by a flap of healthy vascular skin and fat.

FIG. 29

Cross-leg flap over compound fracture of the left leg, with loss of soft tissue and of bone, resulting from a gunshot wound in a hunting accident.

A and *B:* Aspect of wound of the left leg on May 14, 1946, eight months after the accident. Draining sinus, through which sequestra are eliminated, is surrounded by an area of infected and scarred tissue.

C: Appearance on July 16, 1946. Defect has been covered by a cross-leg flap, taken from the posterior aspect of the right leg. Healed donor area on the left thigh is seen. Skin graft was removed to cover the donor area of the flap on the right leg.

D: Aspect of donor area of the flap on the posterior aspect of the right leg. The skin graft of intermediate thickness has given a satisfactory resurfacing.

FIG. 30

A: Roentgenogram showing non-union of tibia with considerable loss of bone. Note hypertrophy of fibula with varus deformity of ankle (from weight-bearing in a brace). (Case shown in Fig. 29.)
B: After transplantation of the fibula into the tibia and filling in of the gap with iliac bone (operation by Dr. T. Campbell Thompson). Note correction of varus deformity of ankle.

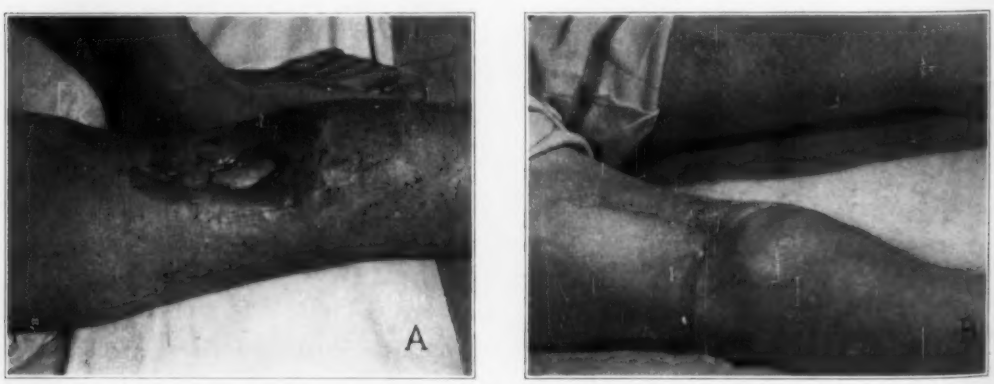

FIG. 31

Transposed flap for defect of the thigh with exposed bone.
A: Defect of the thigh. The uncovered femur is necrosed.
B: Complete closure has been obtained in one stage by complete excision of all scar tissue, resection of all necrotic bone, and covering the area by a transposed flap from the lateral aspect of the thigh. The secondary defect was covered by a free skin flap over the fascia lata.

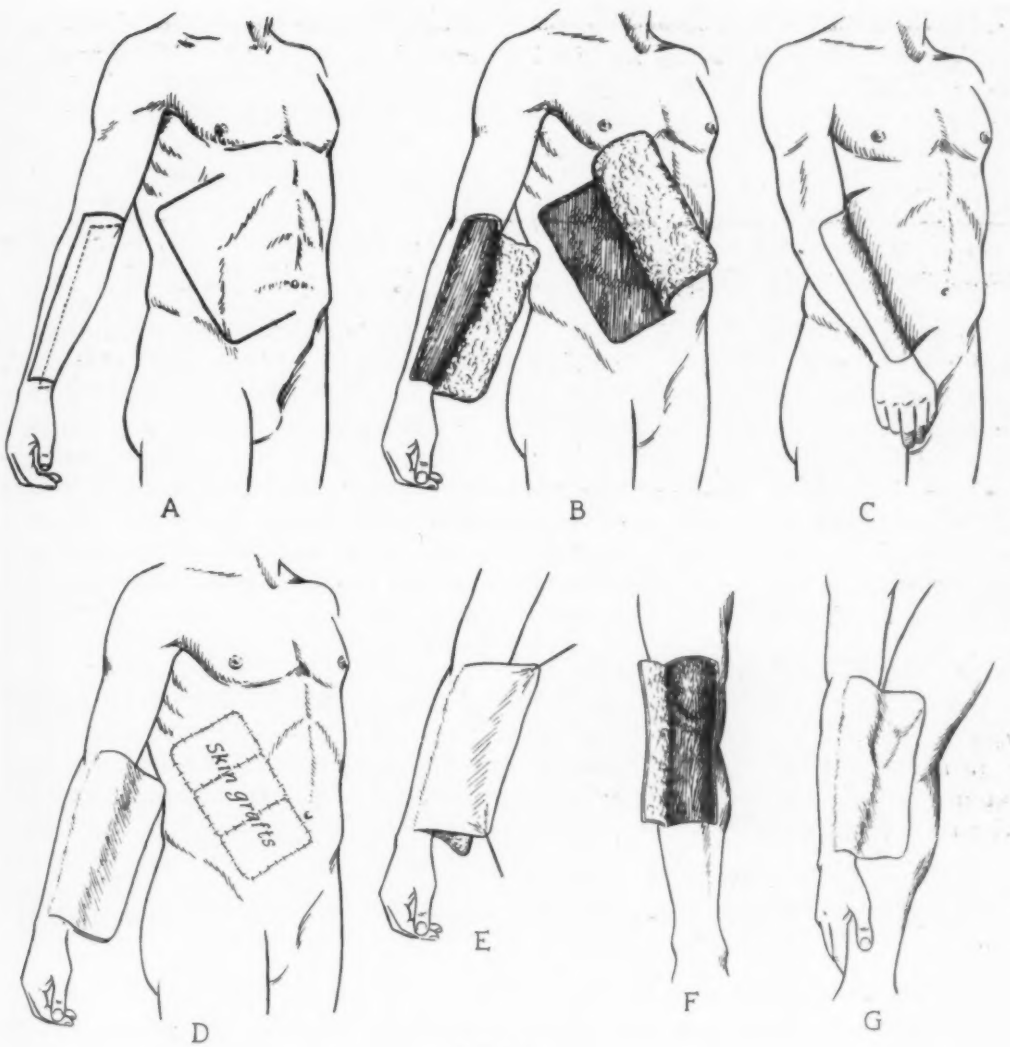

FIG. 32

The closed carried flap.

A: Outline of incisions for the abdominal flap and for the hinge flap on the forearm.
B: The abdominal flap and the hinge flap have been raised.
C: The abdominal flap is attached to the forearm.
D: The abdominal flap has been detached from the abdomen. The resulting raw area has been covered by skin grafts.
E: The carried abdominal and the antebrachial flaps are separated.
F: The scar tissue on the recipient area has been excised.
G: The carried flap is placed over the defect. The remainder of the carried flap will be detached from the forearm, in order to provide covering to the whole of the defect on the leg. The antebrachial hinge flap is then replaced in its original site, as in *A*.

being used,—the two legs are either parallel or crossed (Fig. 23). In a first step, the scarred area is widely excised, and a skin graft of intermediate thickness is removed from the thigh. In some cross-leg flaps, such as in the covering of a heel, the whole procedure can be performed on the patient lying ventrally (Figs. 26-A and 26-B). In most cases, however, it is necessary to turn the patient on the operating table, in order to prepare the flap on the donor leg and to suture the skin graft into place (Fig. 8).

After the pressure dressing has been immobilized by means of sutures, the patient is again turned, and the flap is applied over the defect. Interrupted U-shaped intradermal sutures are placed at regular intervals, so as to produce an accurate apposition of the edges of the flap to the edges of the defect, even without skin sutures, and even when the latter

are of unequal thickness. After the flap has been sutured in place, the lower extremities are immobilized in their position of transfer by a carefully applied plaster. A table of the Hawley type facilitates this procedure. The wounds are not touched until, at least two weeks later, the plaster cast is cut and removed, and the pedicle of the flap is sectioned. During the period of immobilization in plaster, the extremities should be elevated (Fig. 25). This position favors vascular and lymphatic circulation and simplifies the nursing care of the patient.

Various positions of transfer are used, according to the portion of the lower extremity warranting repair:

1. *Flap Repairs of the Foot:*

The covering of the distal portion of the foot (Fig. 28), of the dorsum, and of the heel, over the calcaneus or tendo achillis (Figs. 26-A and 26-B), is readily achieved by using the positions of transfer illustrated. More difficult is the flap repair of the sole of the foot, where the flap must be large in size and must heal *per primam*, so as to provide an unscarred pad of skin which will permit weight-bearing (Fig. 27). The repair of the inner half of the sole of the foot has been best achieved by an oblique flap, raised along the posteromedial aspect of the opposite leg (Fig. 24,*A*). For the transfer of a flap to the outer half of the sole, it has appeared preferable to cross the legs, taking an oblique flap from the posterolateral aspect of the opposite calf (Fig. 24,*B*).

2. *Flap Repairs of the Leg:*

In covering the anterior or medial aspect of the leg, a flap taken from the posterior region of the opposite leg should be used (Figs. 8, 29, and 30). The two legs are held parallel or crossed, whichever position permits the complete covering of the defect. When a flap repair must be carried out in the lateral portion of the leg, it is necessary to cross the extremities (Figs. 8 and 23,*A*).

3. *Flap Repairs of the Region of the Knee:*

A flap taken from the opposite calf will provide a covering, when a local flap taken from the thigh does not suffice.

4. *Flap Repairs of the Thigh:*

In the present series there has not been a single case of the use of a distant flap for a defect of the thigh. Local flaps from the generally abundant tissue of the region, combined with skin grafts, have been used (Fig. 31).

C. *Unusual Types of Flaps*

1. *Extensive Flap Repair of the Lower Extremity: The "Closed Carried Flap":*

By a method which we have called the "closed carried flap", rapid massive-skin covering of the lower extremity has been achieved in four cases. A summary of one of the case histories will describe this procedure:

A patient who had suffered multiple compound fractures of the right tibia twelve years previously, complicated by osteomyelitis, presented a densely scarred area, covering the anterior aspect of the right knee and of the right leg over an area of 12 by 17 inches. The scarred area was extremely unstable and, because of repeated breaking down of the area, was thickly fibrosed. Degenerative malignant changes were feared in the ulcerated areas. The knee was ankylosed in extension, and it was possible to raise the lower extremity without undue discomfort to the patient (Fig. 33,*A*).

In a first-stage operation, a right oblique abdominal flap whose undersurface was covered by a hinge flap from the right forearm was attached to the latter (Fig. 32,*B* and *C*).

In a second-stage operation, three weeks later, this closed flap was detached from the abdomen and carried on the forearm to the right leg, where it covered about three-quarters of the defect, from which the scarred area had been excised previously (Figs. 32,*F* and *G*, and 33,*B* and *C*).

In a third-stage operation, eighteen days later, the flap was sectioned, separated from the arm, and sutured to the remaining defect on the lower extremity.

Such a closed carried flap is a rapid method for the repair of defects of the leg, too extensive to be covered by a cross-leg flap (Fig. 33). Its application is limited, because of the discomfort occasioned by the position of transfer. Tubed pedicle flaps, migrated or carried from the abdomen, constitute the alternate method.

2. *Bipedicle and Multipedicle Flaps:*

In abdominal flaps to the hand and forearm which must extend from the palmar surface to the dorsal surface of the same hand, it is advantageous to be able to lengthen the flap by adding a pedicle.

A circular loss of the forearm may necessitate a skin-flap repair by a bipedicle flap. The flap is made to cover about three-quarters of the circumference,—the dorsal, medial, and lateral aspects of the forearm. The volar surface is applied against the abdominal wall. In a second stage, each pedicle is cut; sufficient length to cover the volar surface is allowed.

D. *Failures in Flap Transfers*

The failures which are met with in the course of the transfer of pedicle flaps may be due to necrosis, to infection of the flap, or to improper postoperative care.

1. *Failures Due to Necrosis:*

Necrosis of the whole flap or of a portion of the flap, generally the distal end, because of a deficiency in the blood supply, may be caused by various technical errors. The *proportions* of the flap may be such that the pedicle is not wide enough to permit the survival of a portion of the flap. A flap with sharp angles survives with difficulty. The size of the flap may be too small. In an effort to provide a covering to the defect, the flap is sutured into position under tension. Marked *twisting*, *kinking* of the flap, or placing the flap under *tension* may occur, either as a result of bad designing and planning of the flap, or because the position of transfer is inadvertently changed, when the immobilization of the donor limb is secured. This is a frequent complication during the application of a plaster for the immobilization of a cross-leg flap. To obviate this danger, the two limbs should be firmly immobilized on an orthopaedic table before the plaster is applied.

Not more than *moderate pressure* should be applied over a flap, lest the venous return be obstructed and superficial necrosis, blistering, epidermal desquamation, or even a loss of a portion of the dermis be the result. A frequent mistake in the covering of poorly vascularized areas is the employment of a *flap that is too small.* It is essential that the scar tissue of such areas be widely excised; and a flap that is to cover an area devoid of a normal blood supply should extend widely into the normal tissue around the defect. In this manner, the flap will derive a sufficient blood supply from the surrounding well-vascularized

FIG. 33

Repair of extensive scarred area of the right knee region and right leg by the "closed carried flap". Chronic osteomyelitis of the tibia had developed.

A: Respective positions of the right upper and lower extremities during the flap transfer.

B: Appearance of the carried flap during the transfer.

C: Aspect of the flap repair of the right lower extremity.

tissue. Failure to provide a wide area of insertion of the flap may result in necrosis of a portion of the flap, when the pedicle is sectioned. Separation and gaping over the secondary suture line after the section of the pedicle of the flap were a frequent complication, when the flap was cut too small. The hinge-flap procedure assists in obtaining a vascularized base of insertion.

2. *Failures Due to Infection:*

Infection in the flap itself is rare, because of its resistance to infection, even when applied over a septic area. We have already discussed the preparation of wounds before the application of flaps. The covering of a grossly suppurating wound by a skin flap is generally a mistake. The flap acts as an obstruction to the drainage of a wound which should be left open.

3. *Failures Due to Improper Postoperative Care:*

After a successful flap transfer, there may occur complications, due to the imprudent treatment of the freshly transplanted tissue. This tissue has been severed from its nerve connections; it presents no sensation, nor do the inactive sebaceous and sweat glands provide the skin with its normal lubrication. The patient may unduly traumatize this insensible patch by exposing it to heat and burning. The burn sustained by laying the foot, newly covered by a flap, over a hot radiator is a typical complication. Even prolonged exposure to the sun's rays may cause desquamation of this already dry and scaly skin.

The vascular connections are delicate for weeks after transplantation; slight trauma may cause ecchymosis, hematomata, blistering, and ulceration of the flap. Due to the peripheral barrier of scar tissue, the venous drainage is sluggish and the lymphatic circulation is re-established only gradually. The venous return from the flap is improved by the wearing of a pressure bandage over the flap for months after the flap transfer. Massage will improve the circulation and hasten the softening of the peripheral scar. After the transfer of a flap to a weight-bearing area, the patient should avoid full weight-bearing for many months, until the peripheral scar has softened and a normal circulation has been re-established within the flap. Care should be exercised in placing secondary incision lines and in undermining flaps at the time of a subsequent operative procedure,—such as a bone-grafting. Necrosis of the flap may occur, if an incision is placed in the center of the flap and if the latter is undermined laterally. The flap is then left hinged upon lines of scar tissue, and the blood supply is insufficient. Furthermore, even if healing takes place without incident, the presence of three scar lines, instead of two, does not enhance the circulation of the flap. It is essential, on the contrary, that the secondary incisions be placed in former suture lines and that not more than one-half of the flap be raised, the other half being left attached to maintain the blood supply.

APPLICATIONS OF PEDICLE FLAPS TO THE COVERING OF BONE

The covering of bone constitutes one of the most important indications for the employment of pedicle skin flaps. Such flaps may be required for the covering of bone, denuded by the avulsion or the crushing of the overlying soft tissue; for the covering of fractured bones in compound fractures; and for the replacement of unstable, insufficiently protective, inadequately vascularized scar tissue for the resurfacing of areas of traumatic osteomyelitis and of bone cavities. A special application in this series has been the covering of the defect resulting from leg-lengthening.

A. *Early Covering of Denuded Bone*

The covering of unfractured denuded bone can often be carried out in the early stages by local transposed or rotation flaps. When the patient's condition does not permit a flap operation, or if the tissues in and around the wound are unsuitable for a flap, or if the

wound is too extensive to permit a local flap, a temporary covering can be obtained by the immediate application of a skin-graft dressing. At a later date, this skin graft can be replaced by a flap, either local or taken from a distance.

In compound fractures, when a flap operation is required, the suitable tissue for this procedure should be chosen. A discussion on the treatment of compound fractures is outside of the realm of this paper. Briefly, in compound fractures, the decision to execute an immediate pedicle flap will depend upon the type of wound inflicted. When the compound fracture is seen early, when a thorough excision can be performed, when no foreign bodies (such as earth or bits of clothing) have been pushed into the depths of the wound, the closure of the wound by a local flap, after the reduction of the fracture, followed by penicillin therapy, appears to be indicated. When such conditions do not exist, the flap operation should be postponed until the possibility of suppuration has passed, or until it has ceased. The closure by a flap of such an infected wound would only cause an obstruction to the surgical drainage of the wound and would lead to further necessary operative treatment of the wound. The problem of covering an extensive wound, requiring a flap from a distance, such as a cross-leg flap, is bound up with that of immobilizing the fracture. In such cases, an external skeletal-fixation apparatus was used until the flap transfer had been completed.* The external-fixation apparatus could then be removed and a plaster cast applied.

B. *Replacement of Unserviceable Scar Tissue over Bone*

The need for bone to be covered by well-vascularized tissue was well demonstrated in the present series by the spontaneous consolidation of six non-united fractures of many months' standing, after the transfer of a pedicle flap over the fracture site. Flap transfers were required to replace scar tissue over the heel and sole of the foot. Such scars not only were unstable, breaking down repeatedly under functional stress, but painful, because of the absence of the fat pad. Large flaps transferred by the cross-leg method, after wide excision of the scar, gave lasting repair. However, in weight-bearing areas, it was necessary to exercise great prudence before full functional activity was permitted, lest a breakdown of the flap occur. At least two months should elapse after the flap has healed, before the patient is allowed to walk. Normal activity should not be permitted until six months after the operation.

C. *Pedicle Flaps in the Treatment of Traumatic Osteitis and Osteomyelitis*

The successful treatment of traumatic osteitis and osteomyelitis is dependent upon the provision of an adequate soft-tissue covering of the bone. In the early phase, after the bone has been exposed by the avulsion, laceration, or crushing of the overlying soft tissues, one may be dealing with a simple osteitis, due to the necrosis of the cortex deprived of blood supply. The early resection of the devitalized bone and the immediate covering by a pedicle flap were followed by success in all of the eight cases of this series in which this condition was met.

In chronic traumatic osteitis and osteomyelitis, the following procedure was carried out: All of the necrotic and scarred soft tissue was widely excised, the sequestra were removed, and the devitalized-appearing bone was resected until normal-appearing bone was exposed. At this stage, the exposed bone must be covered by soft tissues, if further necrosis of the bone is to be avoided and a recurrence of invasive bone infection is to be prevented. For this reason, such areas were covered immediately with a pedicle skin flap. Accompanying penicillin therapy was instituted in all such cases. Most of the cases of chronic osteomyelitis seen had been treated over many months by conservative methods,—immobilization of the extremity, packing of the cavity with vaseline gauze, and removal of sequestra. In chronic osteomyelitis, there is often dense scar tissue over the bone. There

* The Roger Anderson apparatus was used in six cases.

FIG. 34

"Accordion" flap for leg-lengthening.

A: Shortening of ten centimeters of the right leg followed compound comminuted fractures of the tibia and fibula, with loss of bone.

B: Lengthening of nine centimeters was obtained after excision of fibrous tissue, cross-leg flap (accordion flap), and traction. (Patient was treated in collaboration with Dr. Merle d'Aubigne of Paris.)

are two causes for this fibrosis. The first is that scar tissue is laid down in the granulation tissue which forms to cover the bone. Epithelium grows slowly over such granulations and, when the wound is an extensive one, the fibrotic changes, which appear in four or five weeks, may be marked [2]. The second cause is the fibrosis which is produced by suppurating sinuses through the skin. In ninety-eight such cases, a wide excision of all of the scarred skin and underlying fibrotic tissue was done; the devitalized-appearing bone was resected; and a flap covering of the area was made. In some cases, the suppuration, which had continued over a number of months, ceased only when this method was carried out.

D. *Pedicle Skin Flaps in the Treatment of Bone Cavities*

The covering of areas of bone presenting depressions, saucerized cavities, or cavities resulting from loss of bone through sequestration presents special problems.

Mention was made previously of skin grafts applied to bone cavities as a first step to obtain a healed wound. In a second stage, the skin graft was excised, and a pedicle flap was used to give permanent repair (Fig.9-C). The author feels that this first-stage skin graft may be dispensed with, and that a flap may be transferred immediately over a saucerized area.

In dealing with deep bone cavities, there may be a dead space between the flap and the bottom of the bone cavity in which exudate will collect. A draining sinus will often follow such an accumulation of fluid beneath the flap. The problem is to eliminate this dead space. When the cavity is not very deep, it may be saucerized to enable the flap to apply itself into the bottom of the cavity. When the cavity is too deep to be saucerized in this manner, it may be obliterated with bone chips. The bone lining the cavity is resected, until normal-appearing bone is exposed. The cavity is then tightly packed with bone chips, and covered by a skin flap. The preliminary temporary lining of such a cavity by a skin graft, to provide a healed dry wound, would appear to be good surgery. The skin graft is excised when the bone-grafting is done. However, in two recent cases, chip-bone-grafting of draining cavities, followed by a resurfacing by a skin flap, was successful.*

E. *Pedicle Skin Flaps in Leg-Lengthening: The "Accordion" Flap*

The following technique was used in three patients who had suffered shortening of the leg, as a result of loss of bone of the tibia and fibula and of soft tissue, following improperly treated gunshot wounds.

A flap of a special design, the "accordion" flap, was used to provide sufficient skin covering to permit leg-lengthening. All of the covering scar tissue was resected. The fibrous tissue between the fragments was excised, and immediate lengthening, varying from one

* In a recent case, treated in collaboration with Dr. P. D. Wilson, a draining bone cavity (5 by 4 by 3 centimeters in size) of the lower third of the tibia was successfully obliterated by chips of refrigerated homologous bone from the bone bank at the Hospital for Special Surgery. After the cavity had been filled with bone chips, a rotation flap from the lateral aspect of the leg was transferred over the area.

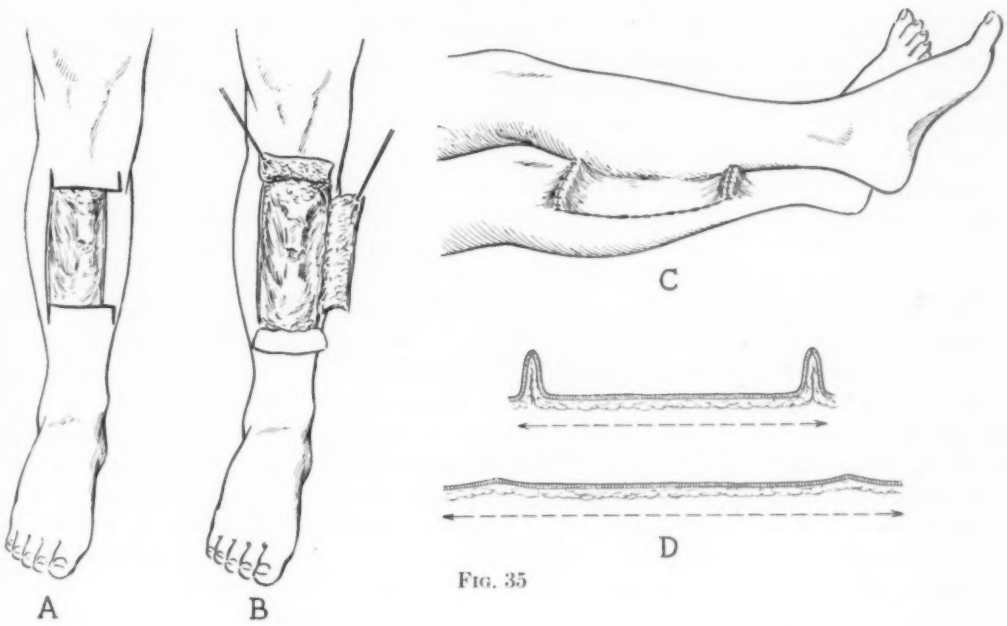

FIG. 35

Fig. 35: "Accordion" flap.

A: Outline of hinge flaps.

B: The hinge flaps are raised.

C: Accordion cross-leg flap in position.

D: Lengthening obtained by the accordion-flap method.

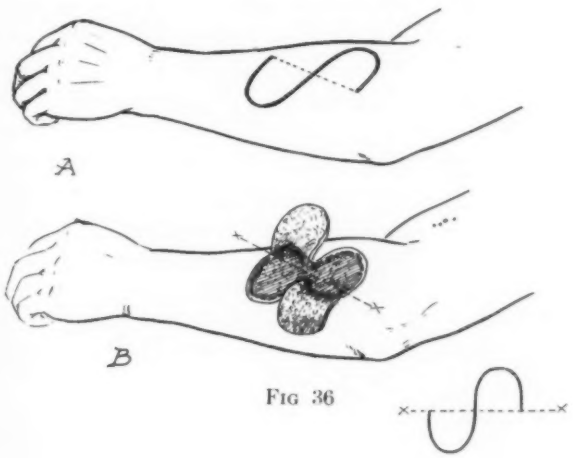

FIG 36

Fig. 36: S-shaped flap for simultaneous covering of dorsal and volar defects of the hand, following through-and-through perforating wounds.

A: Design of S-shaped flap.

B: The flaps are raised. The ulnar border of the opposite hand is placed along the line *xx*.

to three centimeters, was obtained by traction on the lower leg. Further progressive lengthening over a period of two weeks was achieved by continuous traction by means of a transcalcaneus pin. The problem of replacing the deficient soft tissue is twofold: A covering of the exposed bone must be done immediately, and subsequently the tissue thus transferred must be able to withstand the gradual lengthening of the leg, which in one case attained eight centimeters (Fig. 34). A reserve of cutaneous tissue was formed by designing and transferring the cross-leg flap, after raising three hinge flaps,—one medial, one superior, and one inferior (Fig. 35). This "accordion" flap permitted sufficient stretching to achieve the maximum lengthening of the leg.

THE APPLICATION OF PEDICLE SKIN FLAPS TO THE COVERING OF TENDONS IN RECONSTRUCTIVE SURGERY OF THE HAND

In traumatic lesions of the hand, aside from injuries to the bones and joints, the severance of tendons and the loss of skin covering are frequent. They generally result in the binding of the tendons by scar tissue, which prevents their normal play. The complete excision of all scar tissue is the first requisite in the liberation of the gliding structures of

the hand. This excision often results in extensive defects of the hand. The freed tendons must be covered by cutaneous and subcutaneous tissue, because they must be placed in a medium of adipose tissue, which alone will permit their gliding. The presence of fat around the tendon is the prime condition for the success of tendon surgery, whether it be the simple freeing of the tendons, tendon sutures, or a tendon graft. When tendon-grafting is necessary after wounds causing a loss of tendon substance, a preliminary flap repair of the scarred skin may be necessary to obtain the complete mobilization of the finger joint before the tendon-grafting is performed at a later stage. When tendons have been sectioned, they can be strung through the fat with the Blair fascia lata needle. When this procedure is not feasible, longitudinal incisions can be made in the fat, the two lips of the incision being brought around to surround the tendon. The complete insulation of the tendon by the adipose tissue of a pedicle flap may be insufficient, so that it may be necessary to cover the undersurface of the tendon with loose intercellular tissue, removed from over the fascia lata or over the triceps at the olecranon. A typical war injury is the through-and-through bullet or shrapnel wound of the hand. This lesion may result in a complete fixation of the hand, extensors and flexors being equally bound in scar. The one-stage freeing of all structures, volar as well as dorsal, and the covering of both surfaces of the hand by S-shaped flaps on the opposite forearm permit the gradual mobilization of the hand and, later, further reconstructive procedures (Fig. 36).

THE APPLICATION OF SKIN FLAPS FOR NERVE REPAIR AND SKIN REPLACEMENT, IN ONE STAGE

The necessity of plastic repair of the scarred cutaneous covering in peripheral-nerve lesions is well recognized. The usual procedure entails two separate stages; first the plastic repair of the scarred skin is carried out, followed in a second stage by the repair of the injured nerve. Thus a delay of weeks or months may occur before the nerve lesion is treated. It was observed that in a large proportion of such cases it was possible to perform the repair of the soft tissues and of the nerves in a single stage. After the complete excision of the cutaneous and subcutaneous scar and the liberation of all of the structures incorporated in the scar, the repair of the nerve is done. The surface defect is then covered by a flap of skin and subcutaneous fat, raised from the deep fascia and taken either from the adjacent area or at a distance. This single-stage combined operation presents the following advantages:

1. Less scar tissue is laid down in the wound than when two separate operations must be performed.

2. The date of the nerve repair is advanced, thus reducing the period during which progressive atrophy of the denervated end organs and muscles takes place. Recent experimental work has stressed the importance of early nerve repair.

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THE FORMATION OF NEW BURSAE WITH CELLOPHANE*

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Fibroblastic proliferation is a reaction of normal tissue to trauma. This may be beneficial, as in the case of wound healing. It is undesirable when it leads to scar formation, especially when this scarring hinders the function of any part of the body. Operative trauma to a synovial surface is apt to be followed by adhesions. These may be overcome by early use of the affected part. However, if the operative trauma has been severe, or if the operation has included the excision of the synovial surface, the postoperative scarring may permanently limit the function of the part.

The purpose of this paper is to present the gross and microscopic studies of cellophane implantation into the sites of the subdeltoid bursae of rabbits, after these bursae had been obliterated by postoperative scarring.

Donati, in 1937, first reported the use of commercial cellophane, 0.02 millimeter in thickness, to prevent adhesions between the brain and the skull. After thirty-five days the cellophane was found to have no irritative reaction surrounding it. Wheeldon used cellophane in tissues, and was satisfied with the clinical results obtained. He had no postoperative gross or microscopic observations on the tissue reaction. He quotes a personal communication from Dr. A. W. Farmer of Toronto, who, in animal experiments, had noted no foreign-body reaction of the tissue to the cellophane.

McKeever used cellophane after synovectomy of the knee, in order to maintain the suprapatellar pouch. He obtained permission from a patient to re-explore his knee two months after cellophane implantation. He found a smooth, glistening tissue surface. He had used No. 300 P.U.T. and concluded that there was no tissue reaction to it. This was confirmed by microscopic examination. By the use of this method, flexion of the knee of 90 degrees was easily obtained by the end of the first week, with a minimum of effort on the part of the patient. Other types of cellophane may have a directly opposite reaction on tissues, and some observers have used this material in an attempt to stimulate the production of excess connective tissue.

Pearse, Harrison and Chandy, and Poppe and de Oliveira have used cellophane to cause obliteration or narrowing of aneurysms of the aorta and the subclavian artery. Harper and Robinson have employed cellophane to cause obliteration of a patent ductus arteriosus. Page and Graef reported the occurrence of perinephritis and hypertension, following the wrapping of one or both kidneys in cellophane. These authors wrapped either the aorta or kidney in cellophane of various types. It was sterilized by soaking in alcohol or mercury oxycyanide for twelve hours preoperatively.

Cellophane, in these cases, produced scarring. There was an immediate marked tissue reaction, which progressed to massive scarring in three to five weeks. Poppe explains the apparent contradiction in these two types of reaction to cellophane. There are chemically different types of cellophane produced commercially. These are varied still further by the application of many types of protective coatings, which add such qualities as moisture resistance and heat sealing.

MATERIALS AND METHODS

The site of the subdeltoid bursa was explored in thirty-five rabbit shoulders. These bursae had been obliterated by scar tissue, which had resulted from two previous operations, performed during the course of another experiment. The first operation consisted in

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traumatizing the floor of the subdeltoid bursa and the supraspinatus tendon. The second operation was performed to remove the supraspinatus tendon for microscopic examination. The end result was a complete obliteration of the bursa by scar tissue. It was decided that this scarred area would be a good area for testing the ability of an inert material, such as cellophane, to form a new bursa lined with a synovial surface. Accordingly, a third operation was performed, in which the scarred area of the subdeltoid bursa was dissected to form two layers. Between these two layers a sheet of No. 300 P.T. cellophane was placed. The roof of the bursa and the skin were then closed in separate layers, by the use of fine black silk.

The cellophane was sterilized by placing a sheet, about four inches square, between two heavy sheets of brown paper and rolling these to form a cylinder, which was autoclaved for twenty minutes. It was found necessary to employ heavy, smooth paper to prevent the cellophane from becoming wrinkled during autoclaving. At operation, circular pieces of cellophane, about one and five-tenths centimeters in diameter, were cut from the big sheet, and were used to separate the two layers of scarred tissue. No fixation was used, the cellophane being merely laid flat in the prepared site. The cellophane was left in the tissues for periods varying from 29 to 149 days, before being removed for study.

Intravenous nembutal anaesthesia was used routinely, supplemented by open ether if required. After the hair had been removed with sodium sulphide, neutralized with 15 per cent. acetic acid, the skin was prepared with iodine and alcohol.

OBSERVATIONS

Five of the operative sites became infected; so these rabbits were discarded, leaving thirty cases from which to draw conclusions regarding the effectiveness of cellophane.

Gross Observations

Twenty-three cases showed a bursa of normal appearance, one and five-tenths to two centimeters in diameter, lined with a shiny, glistening wall. The cellophane was as soft and as pliable as when it was inserted. In three of these cases there was no evidence of the cellophane, although a good bursa was present. It was thought that the cellophane had rolled up late in the process of bursa fomation, and had been extruded through the bursal roof and skin.

In five cases, the cellophane had become rolled up into a ball or a cylinder, and lay in a small sac, lined with a shiny, glistening wall. This sac was usually one to three millimeters in diameter. The sac containing the cellophane lay either in the position of the subdeltoid bursa or just beneath the skin. The pieces of cellophane which had become rolled up into a cylinder were those which were found just beneath the skin, having eroded through the roof of the bursa and the deltoid muscle.

In two cases no new bursa was found. In one of these no cellophane was found; and in the other, the cellophane was found as a tightly coiled cylinder, half extruded through the skin. It was pulled out easily, no force being required.

Microscopic Observations

Twenty-three sections showed a good synovial lining. Two, which were taken from a rabbit that had died the previous day, showed poor tissue outlines. A surface could be made out, but it was not clear-cut. In three sections the bursal surface was missed in cutting the block. The two cases in which gross examination disclosed no bursa formation showed, of course, no synovial surface microscopically.

The microscopic appearance of the newly formed bursae conformed very well to the description given by Key for normal synovial surfaces. In sections taken through the roof or floor of the bursa, the newly formed surfaces were typical of the areolar type of synovial surface (Fig. 1). There was a well-defined surface layer supported by loose areolar connec-

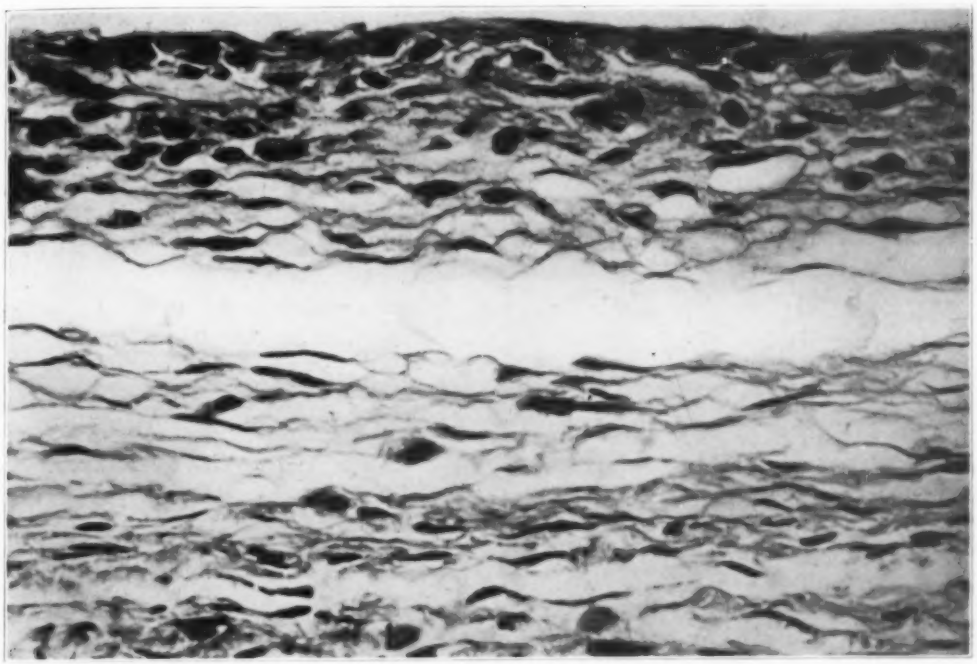

FIG. 1

High-power view (×400) of a newly formed synovial lining. There is a well-defined surface layer supported by loose areolar connective tissue. The cells lie in a collagen matrix. The nuclei of the surface cells are plump, while those of the deeper layers become more oval and, finally, elongated, with their long axis parallel to the surface lining.

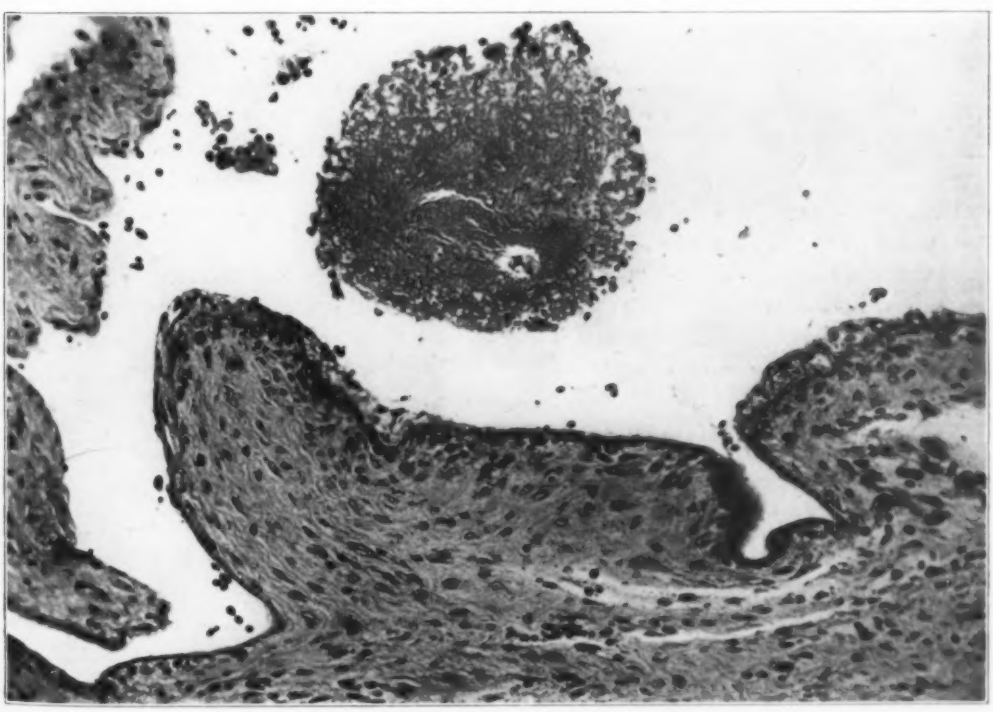

FIG. 2

Villous formation. Villi show the same structure as the flat synovial lining. Some fibrin and occasional macrophages are also seen (×120).

FIG. 3

Cellophane *in situ*. The cellophane is seen as a relatively translucent band. There is no evidence of fraying or destruction of the cellophane. The newly formed synovial surface is seen lying on a base of denser connective tissue (×250).

tive tissue. The cells were imbedded in a collagen matrix, and lay either partially on or beneath the surface. The depth of this surface layer varied from one layer of cells to many layers. The collagen matrix varied from loose to slightly compact. Usually there were no villi present, but occasionally there were a few (Fig. 2). These villi were of the same structure as the flat synovial layer. The surface cells were flat, and lay imbedded in a loose collagen matrix. The deeper cells were more spindle-shaped, and lay with their long axis parallel to the bursal surface. On the surface of the synovial membrane, there was occasionally a thin layer of fibrin. In this layer there were apt to be a number of macrophages. Rarely a polymorphonuclear leukocyte was seen around the surface layer. Underneath the surface layer were a varying number of small blood vessels. Sometimes these were profuse, and sometimes almost absent. In several specimens the bursa was excised intact, to preserve the cellophane within the bursa (Fig. 3). In sections of these bursae, the cellophane showed up under the microscope as a definite, but relatively translucent, band. There was no fraying of its surface or any sign of fragmentation. The underlying synovial surface appeared as described. In several of the sections through the floor of the bursa, a denser type of collagen, forming the base of the bursa, was found. Figure 4 shows one of these sections, with the coiled cellophane lying within the bursa. This bursa had been excised intact, without being opened. The lining wall was smooth, in spite of the coiling of the cellophane. The linings which grossly appeared normal showed a good synovial lining under the microscope.

The only evidence of foreign-body reaction encountered was giant cells surrounding suture material, which was fragmented in the process of absorption.

COMMENT

In the infected cases, the infection was not due to foreign-body reactions, because, in three of the five rabbits with infected shoulders, a normal new bursa had formed on the opposite side. All presented the gross and microscopic picture of pyogenic infection.

McKeever has stated that he found evidence of fragmentation of cellophane in his study of one case. He used No. 300 P.U.T. cellophane. If one might draw an analogy, from the rapidity with which silk suture is phagocytosed in rabbits, it is probable that cellophane destruction would be much more likely, and more rapid, in rabbits than in humans.

Key states that synovial-membrane cells are fixed connective-tissue cells, which are modified slightly because of their position. He points out that the lining cells of joint and

FIG. 4
Coiled cellophane lying in the bursa (×120).

bursal cavities differ embryologically from the cells lining the primary body cavities. This being the case, one would expect connective-tissue cells to be able to reform a synovial lining very similar to the original. The pictures reproduced here correspond closely with the normal specimens presented in Cowdry's textbook of histology, and also with the normal picture observed during this study.

Cellophane allowed the formation of a grossly normal subdeltoid bursa, with a glistening synovial lining, in twenty-eight out of thirty cases. In five of these, the size of the synovial cavity was diminished, due to folding of the cellophane. If a larger piece of cellophane had been used, or if it had been fixed at the edges so that it could not fold, this complication might not have occurred. That this synovial lining would not have resulted from simple dissection of the space and subsequent closure is evident from the fact that two previous operations resulted only in progressive scarring, and finally in complete obliteration of the subdeltoid bursa. It is quite possible that, if cellophane is used in human surgery, it should be removed through a small stab incision, after the new synovial lining has formed. The longest period of observation in these cases was 149 days. There was no sign of reaction of the tissues or degeneration of the cellophane. What would happen if it were left in human tissues for years is, of course, unknown. If the cellophane were excised through a small stab incision, and the bursa functioned in the usual manner, it would probably remain patent. In the three cases in which the cellophane extruded late in the process of bursa formation, there was no sign of subsequent obliteration of the bursa.

The cellophane extruded spontaneously through the skin by rolling up to form a cylinder, and pushed out by eroding the tissues with the sharp point so formed. This is another argument for fixing the edges of the cellophane to prevent it from rolling up to form a useless and potentially dangerous migrating foreign body.

Other writers have described a fibrotic reaction, following the use of 300 P.T. cellophane. Their technique has differed in two respects from that used in the present study. They sterilized their cellophane by immersion either in alcohol or mercury oxycyanide.

This may possibly have changed the chemical composition of the cellophane. They also wrapped the tissue in question in several layers of cellophane, thus partially occluding the blood supply. In performing experimental tendon sutures, the writer has not had very favorable results when the tendon was completely enveloped in a wide tube of cellophane. In this present study, the cellophane was laid flat between two opposing surfaces. The new synovial membranes so formed did not differ either grossly or microscopically from the normal synovial lining of joints and bursae. The cellophane in these experiments acted as an inert substance in the tissues.

SUMMARY AND CONCLUSIONS

1. Cellophane was effective in the formation of a new subdeltoid bursa in twenty-eight out of thirty cases, in which two previous operations had produced only scar tissue which had obliterated the bursa. In the two cases in which new bursae were not formed, the cellophane had coiled up and had been extruded.

2. Grossly, the new bursae were lined with a shiny, glistening wall. The cellophane lay in this new bursa with no gross evidence of foreign-body reaction in the tissues or of destruction of the cellophane.

3. Microscopically, the lining of these newly formed bursae differed in no way from the lining of normal bursae. There was no microscopic evidence of foreign-body reaction, or of fragmentation or destruction of the cellophane.

4. It is concluded that cellophane is a safe inert substance to use in the tissues. It will allow the formation of a new synovial membrane in areas where scarring is to be expected.

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INTERINNOMINO-ABDOMINAL AMPUTATIONS

Report of Twelve Cases*

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The interinnomino-abdominal amputation has been in use, although not commonly, since its introduction by Billroth almost sixty years ago. His patient died a few hours after the operation had been completed, apparently as a result of shock. Girard, in 1895, is credited as the first surgeon successfully to perform an interinnomino-abdominal or hindquarter amputation. Since Billroth's case, approximately 130 cases have been reported in the literature. Prior to 1934, the operative mortality for this procedure was about 60 per cent. Since that time, the mortality rate has been less than 20 per cent.; this remarkable improvement is attributable to the use of transfusions and supportive measures[1]. Most of the reported amputations have been done for sarcoma. Tuberculosis of the hip early contributed a few cases, and other chronic infectious processes have been responsible for a few more. Metastatic carcinoma was found in one of Morton's cases, and the only fatality reported by King and Steelquist followed an amputation for rapidly spreading gas gangrene.

The first interinnomino-abdominal operation performed at the Mayo Clinic was in March 1943, and the second was in August 1943. A report of these two cases was published in 1944 by Ghormley, Henderson, and Lipscomb. One such amputation was done at the Clinic in 1944; two were done in 1945; and seven have been done so far in 1946, which brings the total to twelve.

The most common pathological condition encountered in this series of twelve cases has been the chondroma and osteochondroma group of tumors. These tumors, especially the non-pedunculated ones and those involving the bones of the pelvis, frequently have been difficult to eradicate. When they involve the hip, pain may be severe and the tumor may be small and hard to demonstrate. In the past, wide local excision was the accepted treatment; but it was found that the lesions almost invariably recurred. These recurrent tumors frequently grow rapidly and may attain great size. Malignant change has been reported when these tumors are not removed completely.[2] Of the twelve cases in this series, eight operations were performed for chondroma and osteochondroma, including Grade 1 and low Grade 1 chondrosarcoma and osteochondrosarcoma. Two operations were performed for osteogenic sarcoma and one each for myxofibrosarcoma and fibrosarcoma.

The operative procedure used in the twelve cases which form the basis of this report was essentially the same as that described by King and Steelquist. The method of making the flaps in one case was modified, because of the location of the tumor in the buttock. Another patient required a second operation for complete excision of the tumor, which filled the pelvis. This tumor was removed a month later.

Transfusions were carried out during each operation. The total amounts varied from 1,000 to 3,500 cubic centimeters. Two patients received an additional 500 cubic centimeters during the first twenty-four hours after the amputation. It has been apparent that several of these patients would not have survived the operation without the excellent assistance of our colleagues in the Section on Anaesthesiology, who gave the transfusions and supportive treatment.

* Read at the meeting of the Clinical Orthopaedic Society, Rochester, Minnesota, October 12, 1946.

FIG. 2

Case 4. Osteochondroma of right acetabulum and head of femur.

FIG. 1

Case 3. Osteochondroma of right acetabulum.

FIG. 4

Case 8. Osteogenic sarcoma, Grade 4, of upper part of right femur.

FIG. 3

Case 5. Osteoporosis of left ilium. Lesion later was proved to be chondrosarcoma, Grade 1.

FIG. 5

Case 9. Osteochondrosarcoma, low Grade 1, of right pubic bone.

FIG. 6

Case 10. Chondrosarcoma, Grade 1, of left innominate bone in region of acetabulum, with extension into pelvis.

Convalescence was essentially uncomplicated. The majority of the wounds healed rather slowly. In two cases, infected hematomata developed, which healed promptly after incision and evacuation. In the case in which it was necessary to make the unorthodox skin flaps, rather extensive necrosis of skin ultimately required skin-grafting. The period of hospitalization ranged from twenty-one to ninety-four days. The shortest period was required by a boy fourteen years old, and the longest by the patient who had to have skin grafts.

All patients survived the operative procedure, and, by latest reports, are still alive. The entire series is probably too recent for proper evaluation. In Cases 1, 3, and 5, the lesion has recurred. One patient (Case 2) has been free of symptoms for three years. The other patients, with the exception of one (Case 4) who was well when last seen, were operated upon less than a year ago. These have been relieved of their pain and for the most part are satisfied with the result. The final evaluation must wait until a few more years have passed.

REPORT OF CASES

CASE 1 (previously reported by Ghormley, Henderson, and Lipscomb). The patient, a man fifty-six years old, was first seen at the Clinic in November 1940. His chief complaint was pain in the upper part of his right thigh, progressive wasting of the extremity, and a limp. Examination revealed limited motion, mainly of rotation and abduction, adduction deformity, muscle atrophy, and diminished reflexes. The results of laboratory studies were within normal limits. Roentgenograms revealed nothing diagnostic. Physical therapy was given in an attempt to control the pain. The patient returned one year later; the pain and other symptoms had not changed. A comparison of new roentgenograms with the old showed evidence of diffuse spotting of the ilium and one region of slight periosteal change, suggestive of Ewing's tumor. Biopsy revealed proliferative villous type of synovitis.

When the patient returned in 1942, his pain was severe and he had been receiving narcotics for its relief. Roentgenograms at this time revealed a destructive lesion of the innominate bone. Another biopsy was performed and the pathologist reported finding a chondrosarcoma, Grade 1. A hindquarter amputation was advised, but the patient decided to wait. He returned and was operated upon March 13, 1943. His convalescence was uneventful, and the wound healed by first intention. When he was seen for his first check-up, he was relieved of pain, but local inoperable extensions of the tumor have developed since that time.

CASE 2 (previously reported by Ghormley, Henderson, and Lipscomb). The patient, a man fifty-one years old, was first seen at the Clinic on March 23, 1943. He gave a history of fatigue and pain in the right thigh. He had walked with a limp for three months. Examination disclosed only atrophy of the right lower extremity. Roentgenograms revealed a cystic tumor, just above and adjacent to the right acetabulum.

On March 27, 1943, an exploratory operation was performed. A diagnosis of chondroma was made on the basis of pathological examination. The contents of the cavity were removed and the cavity was swabbed with phenol. The patient returned in July 1943, because of increasing difficulties. Roentgenograms revealed an increase in the size of the tumor. A hindquarter amputation was advised; this was performed on August 4, 1943. Drainage occurred from the wound, but healing was complete and prompt, after an infected hematoma had been evacuated. The patient was seen again in August 1946; he reported that he felt fine. No evidence of metastasis or of local recurrence could be found.

CASE 3. The patient, a man fifty-nine years old, had noted pain in his right hip and a limp for about six months before coming to the Clinic, on April 19, 1944. Physical examination revealed atrophy of the right thigh and leg, pain on motion of the right hip, and a palpable mass deep in the right buttock, behind the acetabulum. Roentgenograms showed a destructive lesion of the right acetabulum (Fig. 1).

An exploratory operation and biopsy, on April 25, 1944, disclosed an osteochondroma. On May 1, 1944, a hindquarter amputation was performed. Convalescence was uneventful, except for delayed healing of the wound. The patient returned in April 1945, at which time a local recurrence of the tumor was found; this was excised. It was found that the tumor had also extended into the sacrum. Complete excision was impossible. When the patient was heard from last, in December 1946, he was bedridden, had severe pain, and required narcotics daily.

CASE 4. The patient, a man forty-eight years old, was seen at the Clinic on March 23, 1945. He gave a history of pain in the right hip and around the right knee, present since December 1941. At first the pain was intermittent, but since early in 1943 it had been constant and had gradually increased in severity. On

physical examination, muscle spasm, with limitation of rotation and a flexion deformity, was found. The roentgenograms revealed evidence of osteoporosis of the head of the femur and in the region of the right acetabulum. There was also an area in the margin of the acetabulum, suggestive of an osteochondroma (Fig. 2). The possibility of a hindquarter amputation was suggested to the patient and, with his agreement, the region was explored on March 31, 1945. The diagnosis of osteochondroma was confirmed by the pathologist, and the amputation was performed. Convalescence was uneventful. The patient visited the Clinic again in November 1945, at which time he was free of pain. No evidence of recurrence could be found. A letter from the patient, in November 1946, reported that he was still well.

CASE 5. The patient, a man thirty-eight years old, was first seen on February 11, 1942. His symptoms —pain and stiffness of the left hip—were of about six months' duration. The findings on physical examination were limitation of rotation, abduction deformity, and pain on motion of the hip. Roentgenograms showed evidence of osteoporosis of the bones of the hip and widening of the articular space (Fig. 3). Traction was applied, and the pain was somewhat relieved. The patient returned in July 1942, and the region of the hip was explored, but the hip was not dislocated to examine the inside of the acetabulum. A specimen was removed and the pathologist reported it to be fibrous inflammatory tissue. The patient again returned, and at rectal digital examination a mass was palpated on the inner wall of the left ilium. A diagnosis of cellular chondroma was made at exploratory operation, and the lesion was curetted out on March 3, 1945. The patient returned for re-examination in October 1945, at which time a recurrence of the tumor was found. A hindquarter amputation was suggested; this was carried out on October 22, 1945. Following operation, a hematoma developed in the wound; this became infected, but healed promptly after the hematoma had been incised and evacuated. When the patient was re-examined on May 14, 1946, he was free from pain. No evidence of recurrence was found. The patient returned again on February 6, 1947, at which time local recurrence of the tumor was demonstrated.

CASE 6. The patient, a man sixty-one years old, was seen at the Clinic on January 3, 1946. He gave a history of pain below his right knee, which had been present since the preceding spring. In September 1945,

FIG. 7

Case 11. Osteogenic sarcoma in region of right acetabulum.

he had noticed a bump in the right groin which, after biopsy, was said to be cancer. He was given roentgenotherapy, but received no relief from the pain. The tumor continued to increase in size. On physical examination, the large, firm mass on the upper medial portion of the right thigh was readily palpable. The only abnormality found in the laboratory study was an elevated sedimentation rate. Roentgenograms showed the soft-tissue shadow, but no evidence of bony origin. A section of the tumor from the original specimen, removed for biopsy, was obtained for study, and revealed myxofibrosarcoma, Grade 2. As the only procedure available for complete removal of the tumor, a hindquarter amputation was advised; this was performed on January 16, 1946. The patient's convalescence was uneventful, except for slight drainage from the wound. On July 17, 1946, the wound was healed and no evidence of recurrence or metastasis could be found.

CASE 7. The patient, a man fifty-three years old, was first seen at the Clinic on April 14, 1945. He complained of a painful mass in the right buttock; this had been present for about one and one-half years, but recently had grown rapidly. Physical examination showed normal findings, except for the rather large mass. Roentgenograms showed nothing more than the soft-tissue shadow of the tumor. On April 19, 1945, the tumor was excised. The pathologist's diagnosis was myxofibrosarcoma, Grade 3.

The patient returned in September 1945, because of local recurrence of the tumor, and was given roentgenotherapy. He returned again in February 1946, by which time the size of the recurrent tumor had increased. A hindquarter amputation was advised; this was performed on February 16, 1946. Because of the location of the tumor and the previous local excision, the usual posterior flap could not be utilized. In its place, a large anterior and medial flap was used. This sloughed rather extensively, and the defect required skin-grafting for closure. This prolonged the period of hospitalization. In a letter, dated September 5, 1946, the patient's wife reported that the wound was nearly healed, but that the patient still had severe pain and was unable to be out of bed for more than short periods. The patient revisited the Clinic on January 13, 1947, at which time he was free of symptoms. No evidence of recurrence or metastasis was found.

Case 8. The patient, a boy fourteen years old, was first seen at the Clinic on February 18, 1946. He had injured his right hip while playing football, in November 1945. There was little immediate distress, but he noticed that the hip was stiff and that the pain gradually increased. The hip had been immobilized in a spica cast for a month, without relief of pain. The patient had been confined to bed for several weeks.

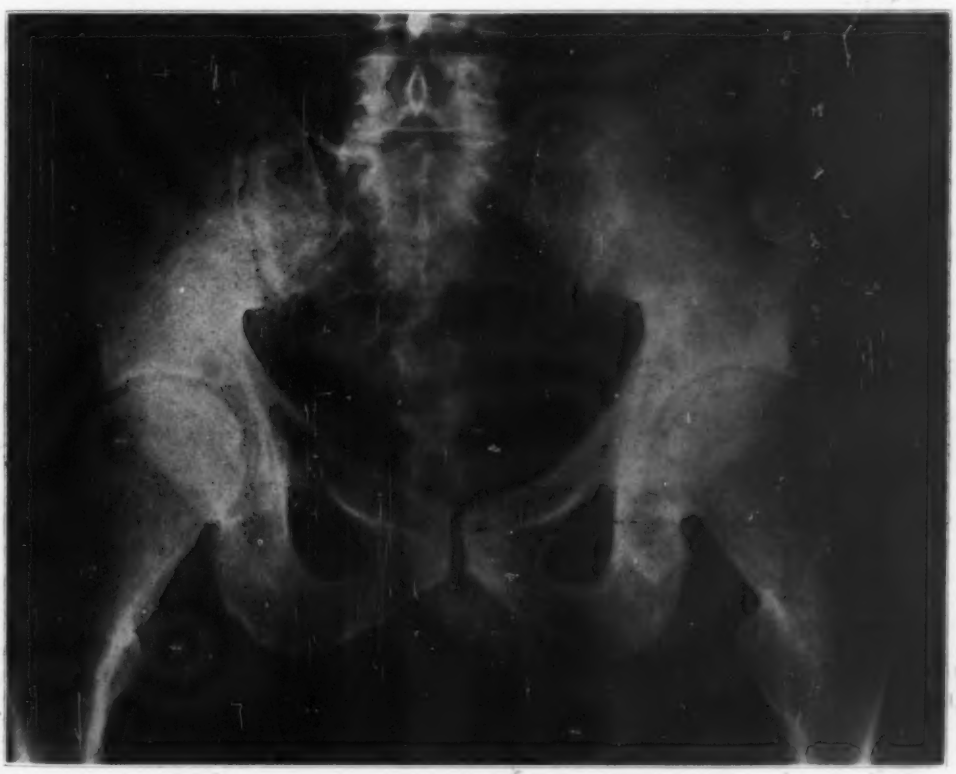

FIG. 8

Case 12. Osteochondroma of the left ilium.

Physical examination revealed a fixed, painful, and swollen right hip. Roentgenograms suggested that an osteogenic sarcoma of the upper end of the right femur was present (Fig. 4). Biopsy was performed on February 20, 1946, and revealed osteogenic sarcoma, Grade 4. In order to relieve the severe pain, a hindquarter amputation was advised; the operation was performed on February 25, 1946. Convalescence was uneventful. The patient was dismissed on the twenty-first day after operation. When he was re-examined, on August 1, 1946, he felt fine, had gained weight, and was walking with the aid of crutches. No evidence of recurrence or of metastasis was found.

CASE 9. The patient, a man thirty-one years old, was first seen at the Clinic in January 1939. His chief complaint was gradually increasing difficulty in emptying his bladder and bowel. By roentgenographic examination, the physician in his home locality had demonstrated a tumor of the right side of the pelvis.

On physical examination at the Clinic, a large, firm mass was palpated over the right pubic bone and, by rectal examination, in the right side of the pelvis. Roentgenograms revealed a large osteochondroma, arising from the superior aspect of the pubic bone on the right side and extending well into the pelvis posteriorly (Fig. 5). On January 19, 1939, the right pubic bone and the tumor were removed. The diagnosis was confirmed by the pathologist. The patient was well for five years and then noted the gradual return of his difficulties. In October 1945, his right leg began to swell. His return to the Clinic, on April 15, 1946, was prompted by acute obstipation, lasting ten days. Physical examination revealed a tumor, filling the entire pelvis. Roentgenograms showed this to be similar to the original lesion. Laboratory studies disclosed nothing abnormal, and there was no evidence of metastasis. On April 25, 1946, the right hindquarter was amputated; in spite of transfusions of 3,500 cubic centimeters of blood, the shock was such that all of the pelvic and abdominal extensions of the tumor were not removed at this time. On May 30, 1946, by an abdominal approach, the remainder of the tumor was removed. The pathologist's diagnosis was osteochondrosarcoma, Grade 1. Except for slow healing of the incision, convalescence was uneventful. The patient reported by letter, on October 1, 1946, that he felt fine, and was back at work as a painter and decorator.

CASE 10. The patient, a woman forty-two years old, was first seen at the Clinic on May 13, 1946. Her chief complaint was pain, which had gradually increased in severity for two years. Roentgenotherapy had given her no relief. Physical examination revealed a soft-tissue mass over the left hip and thigh; and, on pelvic examination, a firm mass was palpated on the left side of the pelvic wall. Roentgenograms gave evidence of an osteogenic malignant tumor, which involved the left innominate bone in the region of the acetabulum and projected into the pelvis (Fig. 6). The results of laboratory studies were within normal limits. A hindquarter amputation was advised; and the operation was carried out on May 23, 1946. The pathologist's diagnosis was chondrosarcoma, Grade 1. Convalescence was uneventful, except for a small hematoma under the flap. In a letter, dated October 1, 1946, the patient reported that she was feeling quite well, with slight pain only at night.

CASE 11. The patient, a woman fifty-four years old, was first seen at the Clinic on May 17, 1946; she gave a history of right sciatic pain of one year's duration. Her condition had originally been diagnosed arthritis and treated as such, but subsequent roentgenograms revealed osteogenic sarcoma.

On physical examination at the Clinic, a tumor could be palpated on the inner surface of the right wall of the pelvis. Laboratory studies gave normal results. Roentgenograms revealed what was thought to be an osteochondrosarcoma of the right innominate bone in the region of the acetabulum (Fig. 7). A hindquarter amputation was advised; and this was performed on May 30, 1946. Pathological examination of the tumor revealed osteogenic sarcoma, Grade 2. Postoperatively, phlebitis developed in a varicose branch of the long saphenous vein in the remaining limb; this subsided promptly after the institution of dicoumarol therapy. In a letter, received October 6, 1946, the patient reported that she felt fine, with mild pain only at night.

CASE 12. The patient, a man forty-three years old, was first seen at the Clinic in March 1944. In 1930, an osteochondroma had been removed from the region of the right hip. Recurrence was noted in this region in 1943, and the tumor had rapidly increased in size. The patient had a moderate amount of pain. This tumor (Fig. 8), including a large portion of the left ilium, was excised on April 3, 1944. Recurrence of the tumor was noted about a year later, and the lesion increased in size. Pain was not severe. On August 22, 1946, when the patient returned, the tumor was the size of a football. Roentgenographic examination revealed an osteochondroma, involving the remaining portion of the left ilium. A hindquarter amputation was advised, and this was carried out on September 11, 1946. The patient's convalescence was uneventful. His wound healed by primary intention.

COMMENT AND SUMMARY

Interinnomino-abdominal amputations have been performed in twelve cases at the Mayo Clinic. It may be claimed that the procedure is too radical to be used for benign

tumors. However, it has been found repeatedly that osteochondromata and chondromata frequently, if not invariably, recur after local excision, and eventually spread to the point where neither local nor radical excision is possible. In four patients, all of whom had fibrosarcoma or osteogenic sarcoma of a moderate to high grade of malignancy, this was the only procedure which would remove the lesion and offer any hope, slight as it might be. In Cases 1, 3, and 5, recurrences of the tumor developed which could not be operated upon.

One patient is well, three years after the operation. The operations on the remainder of the patients have been too recent for any long-range conclusions to be drawn. All of the patients have had a temporary respite from the pain, which has been a symptom common to nearly all of them.

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SENSORY DENERVATION OF THE HEEL FOR PERSISTENT PAIN FOLLOWING FRACTURES OF THE CALCANEUS

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In recent years, it has become increasingly evident that the prognosis in severe crush fractures of the calcaneus is generally bad. This has been the authors' experience. In a clinic receiving many traumatic cases, this fracture has come to be regarded as the "unsolved fracture". Similarly, Bankart has gone so far as to state that his results were "rotten", and he concurred with Watson-Jones in favoring immediate operations for fusion in the treatment of compression fractures of the heel, because of his dissatisfaction with the usual conservative measures.

Numerous methods of managing this fracture have been advocated. As has often been noted in other instances, multiplicity of solutions is usually indicative of discontent. In the hands of the authors, the treatment of the severe "squash" type of fracture, with comminution and involvement of the contiguous joints, has frequently been unsuccessful no matter what method has been used. Nor has triple arthrodesis served to improve materially the late results.

The reasons for these failures merit thoughtful consideration. Any speculation on this point would naturally start with the assumption that the more exact the reduction of the fracture, the better the end result. Hermann has shown the necessity of correcting lateral spread of the heel to avoid subsequent piling up of callus beneath the malleoli.

Böhler's insistence on restoration of the salient angle in the long axis of the calcaneus is well known. Others have emphasized the importance of the integrity of the subtalar and mid-tarsal joints. Despite all this, there are cases in which either the anatomical disturbances have been minimal, or the reduction has been excellent, and yet the patients have been left with disablingly painful feet. Conversely, some of the most severely crushed bones, producing shortened and flattened heels, have been practically symptomless. It is not uncommon to see this paradoxical state in cases of bilateral calcaneal fractures, with marked disparity between the roentgenographic appearance and the clinical status of each foot. Such observations cannot, of course, be explained on a psychological basis, and they have served to establish the conviction that correction of skeletal deformity is not the only objective in these cases.

For these reasons, it was believed that a different approach could be made to the relief of persistent disability following calcaneal fractures. It seemed that even the most severely crushed heel should not alter the integrity of the foot sufficiently to explain the marked symptoms wholly on structural grounds. Apparently, if it were possible to relieve pain permanently, there might be insufficient mechanical hindrance to satisfactory function. A physiological rather than an anatomical solution to this problem was, therefore, sought. Sensory denervation of the heel suggested itself as the answer.

Interruption of peripheral sensation for the relief of intractable pain in peripheral vascular disease of the lower extremities was introduced twenty-five years ago.[5] It is now an established procedure, with clearly defined indications and limitations[4, 6, 7, 8]. Its application, therefore, to the problem of the persistently painful heel after treatment for fracture is logical, direct, and technically simple. Actually, this procedure is readily adaptable to the traumatic foot, since concern over tissue viability, which is paramount in the case of vascular disease, does not pertain here, except in senile patients, who are not frequently involved in industrial accidents.

The tibial and sural nerves are the pathways for the type of pain encountered in these patients. Of these nerves, the latter is purely sensory, but the former also has motor branches to some of the small plantar muscles. There is no significant functional loss due to the division of these nerves. Sensation to the calcaneal region is supplied chiefly by the tibial nerve; the sural nerve's distribution of sensation is limited to only the lateral aspect of the foot. The tibial nerve alone transmits sensation from the joints contiguous to the calcaneus. Since division of this nerve results in anaesthesia of the entire sole of the foot, it would be of some advantage to section only its medial calcaneal branch, if that could be done. Isolation of these nerves is readily accomplished under local novocain infiltration. The technique of the operation has been previously described[4, 6, 7, 8]; in its essentials, this is the operation which was employed in the authors' cases.

Interruption of the sensory innervation of the heel was performed in seven patients.

Case 1. J. F., a truckman, aged thirty-five, was admitted to the Beekman Hospital on November 13, 1940, after having fallen three stories down an elevator shaft while at work. He sustained head injuries, fracture of the body of the first lumbar vertebra, and comminuted, compressed fractures of both calcanei. The heel fractures were reduced and managed in accordance with the Hermann method.

Fourteen months later, on January 20, 1942, the patient re-entered the Hospital. Despite anatomical correction and roentgenographic evidence of healing, he continued to have persistent pain in his heels, particularly in the left heel, when standing or walking. He had done no work since his injury.

Operation: On January 22, 1942, under local anaesthesia produced by 1 per cent. novocain, the tibial and sural nerves were individually isolated through two short vertical incisions in the lower third of the leg posteriorly. The nerves were readily found. After injection of a few cubic centimeters of 2 per cent. novocain into each nerve, the patient was found to have complete anaesthesia over the heel. Deep, as well as superficial, loss of sensation was proved by percussion with a wooden mallet. Since this preliminary procedure had indicated that anaesthesia could be obtained, the nerves were then compressed by hemostats, and two cubic centimeters of 95 per cent. alcohol was injected into each. The skin incisions were closed by fine silk.

Course: Relief of symptoms, following alcohol injection and nerve crushing, was complete but temporary. The patient returned to the Hospital two months later for nerve section (March 13, 1942). Under local

novocain infiltration, the scars from the original operation were excised, the nerves were exposed, and a segment of each nerve, about one inch in length, was removed.

Two months later the patient resumed his former occupation as a truckman. When last examined on October 2, 1945, about three and one-half years later, he stated that he had worked sixteen hours that day. He walked with a normal gait and had good ankle function. There were no trophic changes. Sensation had partly returned, but there had been no recurrence of pain when walking or jumping.

CASE 2. G. H., a stevedore, aged thirty-five, sustained a "squash" fracture of his left calcaneus on March 26, 1941, with marked lateral spreading of the bone. At the same time, he fractured the first lumbar vertebral body. Although fairly good anatomical correction of the calcaneal fracture was obtained, he continued to have persistent pain in the heel when walking, and he remained totally disabled on this account. On October 28, 1942, nineteen months after the injury, he was admitted to the Hospital for block of the peripheral sensory nerves.

Operation: Under local anaesthesia, the left tibial nerve was exposed through a linear incision made posteriorly, just above the level of the ankle. The nerve was isolated, injected with novocain and alcohol, and divided proximal to its medial calcaneal branch. The nerve was then reapproximated by means of fine perineural sutures through the neurilemma. In a similar manner, through a separate incision, the left sural nerve was exposed at this same level, divided, and resutured. In each case, the nerves were readily found, and the procedure was done without trauma to the accompanying blood vessels. Fine silk was used for ligatures and sutures.

Course: Follow-up examination was made on April 5, 1944, eighteen months after the denervation procedure. The patient had resumed work one year previously and had continued at his usual job. He still complained of numbness, which, however, was decreasing. He had no paraesthesia and no evidence of trophic disturbance. He walked with a normal gait and had a full range of motion in his ankle joint and foot. In October 1946, he was doing full-time work as a stevedore.

CASE 3. H. S., aged sixty-five, a laborer, entered the Hospital on May 31, 1943. Sixteen months previously, on January 19, 1942, he had fallen from a ladder, and had sustained compression fractures of both calcanei. He was treated elsewhere by manual reduction and plaster-cast immobilization, followed by a prolonged course of physical therapy. He was referred because of disability, due to persistent pain.

Examination showed moderate flattening of both heels, restricted joint motion, and a defective gait, due chiefly to pain on striking the heels against the floor. Percussion elicited sharp pain. Roentgenograms showed both calcaneal fractures to be well healed, with relatively little lateral spread; the tuber angles were satisfactory.

Operation: On June 1, 1943, the tibial and sural nerves in each leg were individually exposed, isolated, blocked by novocain, and divided. The nerves were not resutured.

Postoperative Course: From a condition of total disability, this man was subsequently returned to industry after sensory-nerve division. His result was regarded as satisfactory by the Federal Workman's Compensation Commission and his "schedule loss" was materially reduced.

CASE 4. J. C., a longshoreman, fifty-nine years old, entered the Hospital on January 31, 1944. In October 1942, he had sustained a fracture of the right calcaneus, for which he had been treated in another hospital by manipulation and plaster encasement, followed by months of care, although he was ambulatory. Bony union had taken place, but the patient had remained incapacitated because of pain in the injured heel.

Operation: On February 2, 1944, the right tibial and sural nerves were exposed, divided, and then reapproximated with sutures.

Course: Complete anaesthesia of the right heel area was obtained. When the patient was last examined in October 1946, sensation had returned without recurrence of local pain. There had been no evidence of trophic disturbance. This man had worked only irregularly since his operation.

CASE 5. J. S., aged forty-six, a longshoreman, was admitted to the Hospital on February 21, 1944, because of a painful right heel, resulting from an old calcaneal fracture. His injury had occurred eighteen months previously. Despite healing of the fracture and good anatomical position, disability was complete.

Sensory denervation of the right heel by division of the tibial and sural nerves was done on February 23, 1944.

Course: When examined two and one-half years after operation, the patient had partially regained sensation in the heel. Pain was not present on walking or striking the heel. He had not resumed work, due, apparently, to dissatisfaction with the legal aspects of his case.

CASE 6. N. D., a stevedore, aged forty-six, was admitted on February 27, 1945. Thirteen months before, while at work, he had sustained a compression fracture of his right heel. His pain had not been relieved by the usual conservative measures.

Section of the tibial and sural nerves was done on February 28, 1945, with excision of about two centimeters of each nerve.

When last examined in September 1946, he complained of paraesthesia in the heel and sole. There had

been some return of sensation, but he had no pain on walking or on direct percussion of the heel. No trophic disturbance had occurred.

CASE 7. M. K., aged forty-six, sustained a compression fracture of the left heel in addition to back and shoulder injuries when he fell into the hold of a ship, while working as a stevedore, on October 30, 1945. His calcaneal fracture was reduced by the Böhler technique. One year afterward, he was still totally disabled because of severe pain.

On November 1, 1946, nerve section was done, and segments of the left tibial and sural nerves were excised. Three months later, he had returned to work at a lighter job. He was entirely free of pain on walking and jumping. His gait was normal.

COMMENT

Seven patients were subjected to nerve section in an attempt to relieve intractable pain and total disability resulting from compression fractures of the calcaneus, sustained in industrial accidents. In all cases, the usually accepted methods of treatment—consisting of manipulative correction or attempted correction of the calcaneal deformity with subsequent plaster-cast immobilization, prolonged periods of rest, and, later, physical therapy—had previously been given adequate trial. In each instance an interval of over one year had elapsed after injury before sensory denervation was undertaken. These patients have been followed for periods of four months to five years after nerve section.

Four of the seven patients have returned to industry,—three to their former heavy occupations, and the fourth to lighter work. In three cases, disability has persisted; or at least these men have been unwilling to attempt work or to admit satisfactory results.

Experience with these cases has led the authors to feel that, while the full solution of this problem has not yet been found, the procedure suggested and tried may help to solve some of the difficulties encountered in fractures of this type. The results seem promising enough to recommend this procedure in certain instances. The selection of cases for this form of treatment should be made with care, and only after an evaluation, based upon the physical, psychological, and social factors peculiar to the individual, has been made. This procedure should be limited to cases of severe crush fractures of the heel, in which other methods have been tried and found inadequate. Furthermore, the patient must be one who has a sincere desire to "get well" and to return to his occupation.

No harmful effects were observed from peripheral-nerve section in any of these cases. No single evidence of trophic change occurred. This experience coincides with those previously reported. In fact, Smithwick and White, with regard to cases of thromboangiitis obliterans, have stated, "After an extremity has been desensitized, ulcerations which previously resisted all methods of treatment will frequently heal". The patient is warned of the necessity for cleanliness and is cautioned to avoid shoe pressure or friction. He is told of the peculiar sensation of numbness that will at first make walking seem strange, and he is cautioned to guard against injury. However, in all instances, sensation, wholly or in part, gradually returned without pain, and the only advice needed was to continue foot hygiene. As far as could be determined, there seemed to be little choice between nerve resection and simple division with resuture. Due to the peripheral site of the operation, it would seem best to remove a small segment of nerve to prevent too rapid recovery of sensation. This procedure is offered as a method of handling a problem that, in many instances, seems otherwise unsolvable at present.

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(*Continued on page 235*)

RESECTION OF THE OBTURATOR NERVE FOR RELIEF OF PAIN IN ARTHRITIS OF THE HIP JOINT

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The treatment of painful hip joints caused by destructive arthritic processes presents a difficult problem to the orthopaedic surgeon.

The purpose of this paper is to describe a simple method which produces relief of pain in a large number of cases, irrespective of the cause of the arthritic changes.

The method was first introduced in France in 1934 by Tavernier, following the procedure suggested in 1933 by Camitz in Sweden. Camitz observed veterinary surgeons performing resection of sensory nerves in the hoofs of horses, and thought of applying the same principle in the treatment of human hip joints. He was the first to report several cases.

Other surgeons in France then used this method of treatment, and they were apparently satisfied with the results. According to Tavernier, treatment consisted in an avulsion of the obturator nerve through an incision over the femoral triangle. The simplicity of the method and the reported relief from pain encouraged the author of this article to operate for the first time on a patient with severe Marie-Strümpell arthritis, involving the spine and both hip joints. The patient had been bedridden for about three months previous to the operation. On October 20, 1945, an avulsion of the obturator nerve through the femoral triangle of the right extremity was performed. The relief from pain was so satisfactory that the patient requested that the operation be performed on the left side. This was done in February 1946. The immediate results from both operations were excellent. Since then, the patient has returned to his occupation as a gardener.

The relief from pain obtained in this case prompted further operations, as well as a more searching investigation of the relation of the obturator nerve to the nerve supply of the hip joint.

The description of the nerve supply of the hip joint varies in the textbooks of anatomy and is incomplete. Neither is the relation of the obturator nerve to the capsule of the joint well described. Tavernier states that the deep branch of the obturator nerve supplies the greatest part of the anterior capsule of the hip joint, the head of the femur, and the acetabulum; and that the articular branches to the anterior capsule of the joint can be visualized in the cadaver and recognized upon operative intervention.

A personal study of the obturator nerve at its exit from under the horizontal pubic arch was made to clarify the problem. Dissection of the articular branches of the obturator nerve is technically very difficult, and requires fine and patient search with the aid of magnification. The articular branches of this nerve were examined on twenty-four cadavera, dissected by the more skillful first-year medical students at the College of Physicians and Surgeons, Columbia University, and also in thorough dissection of four hip joints by the author. Tavernier's description was confirmed to a certain extent. However, it could not be agreed that the articular branches to the joint capsule are easily seen. The illustration (Fig. 1), drawn from one of the specimens dissected by the author, shows the femoral triangle cleared of skin, fascia, and the large vessels and nerves of the region. The pectineus has been divided near its origin, and reflected outward. The horizontal branch of the pubis was resected to expose the obturator nerve in its course from the pelvis into the thigh. The pubofemoral part of the capsule was detached from the pubis, and reflected and rotated so that the antero-inferior part of the capsule is exposed. The largest articular

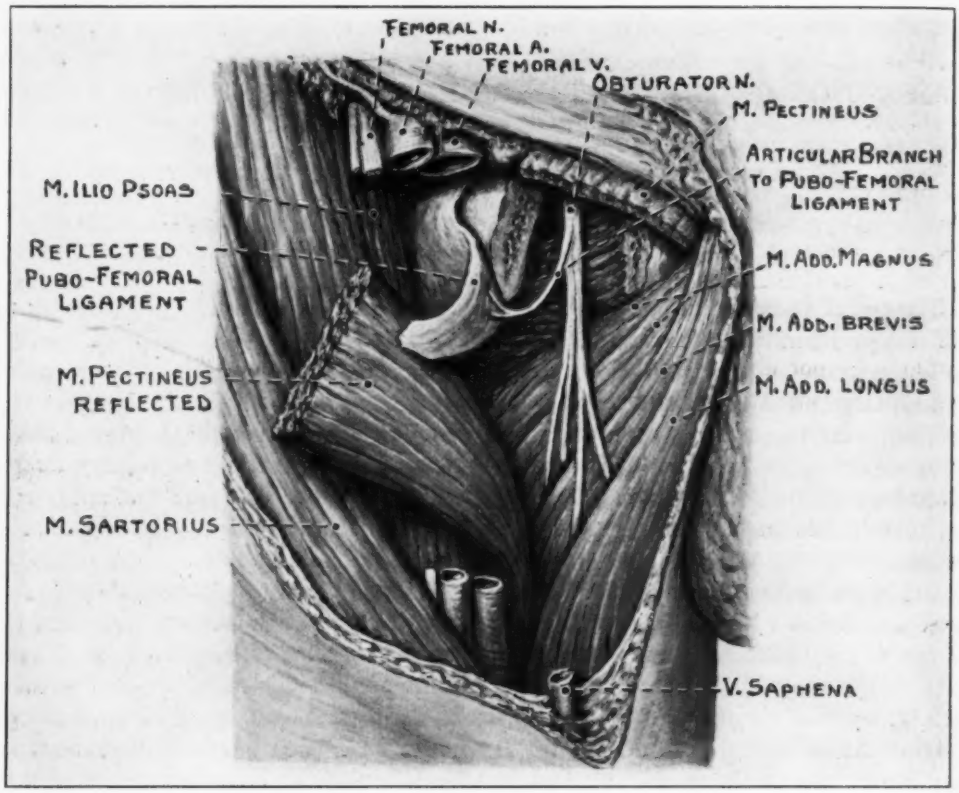

FIG. 1

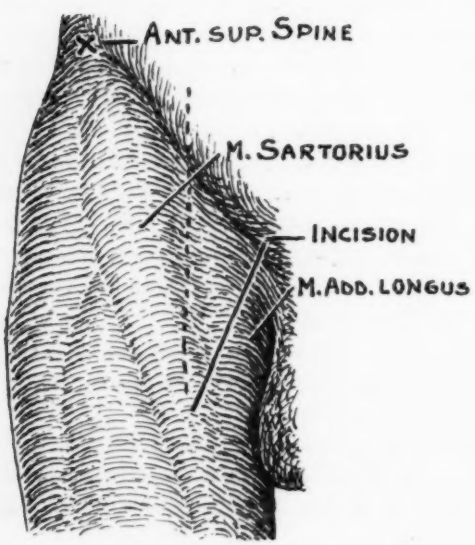

FIG. 2.

branch of the obturator nerve originates from the common trunk, before its division into a superficial and a deep branch. Multiple slender articular branches are also found here. The superficial branch of the obturator nerve is seen to penetrate between the adductor longus and the adductor brevis. The deep branch enters the space between the adductor brevis and adductor magnus. Although this is the most common arrangement, the articular branches to the anterior capsule have also been seen originating from either the superficial or deep branch of the obturator nerve. The other articular branch, frequently described as entering the head of the femur through the round ligament, could not be followed.

The difficulties connected with dissection of the slender articular nerve branches are apparently responsible for the absence of clear information concerning the nerve supply of the hip joint. This nerve supply is generally described as consisting of anterior and posterior branches. The posterior branches arise from the sacral plexus, either directly or through the sciatic nerve, or from the posterior femoral cutaneous nerve. An additional branch is supplied by the nerve to the quadratus femoris. The anterior branches are sup-

plied by the lumbar plexus through the femoral and obturator nerves. Apparently the greatest part of the nerve supply to the joint is derived from the multiple branches of the obturator nerve.

Anatomical dissection showed that the easiest approach to the obturator nerve is through the femoral triangle (Scarpa's triangle). An incision, three to four inches long, is made parallel to the lateral border of the adductor longus muscle, which can be easily palpated, or may be found by connecting the pubic tubercle with the point of intersection of the sartorius, by a descending vertical line bisecting the inguinal ligament (Fig. 2). In the male patient, care must be taken not to divide the spermatic cord near the pubic tubercle. After the skin incision has been made, several layers of fat separated by superficial fascia are encountered, especially in obese patients. These fascial planes are divided, until the deep fascia covering the muscles of the femoral triangle is exposed. As soon as the deep fascia has been recognized, the long saphenous vein is retracted laterally. It should never be retracted medially, as it pulls with it the femoral vein. The saphenous vein may be ligated, if it is in the way. An incision is then made in the fascia, along the lateral border of the adductor longus. The space between the adductor longus and the pectineus muscle is easily found, and is separated bluntly. It may be observed at times that the pectineus muscle is overdeveloped, and hinders the exposure of the obturator nerve. It can easily be divided near its origin from the pectineal line. The separation of these two muscles uncovers a fascial space, usually filled with fat and crossed by vessels deriving from the obturator and the medial circumflex arteries and veins. Ligation of these vessels is a simple and rapid step. By gentle separation of the fat, the anterior branch of the obturator nerve is found and followed to the point of exit from under the superior arch of the obturator foramen. The identification of the articular branches is apparently very difficult. It is best to follow the nerve to the point of exit from the foramen, divide it, and avulse it as high as possible in a manner similar to that followed in phrenicectomy. The avulsion involves the two branches of the obturator nerve. No special closure is necessary. A few sutures in the subcutaneous tissue and skin are all that are required.

Of course, it is possible to approach the obturator nerve through the suprapubic route as described by Chandler, or through a medial incision between the adductor longus and gracilis muscles.

However, as many of the patients with arthritis are in the middle-age group, and are frequently obese, the suprapubic approach is involved and difficult. The relation of the obturator nerve to the artery and veins at the point of its penetration into the obturator foramen from the pelvis is quite inconstant. In the attempt to reach the nerve through the suprapubic opening, injury to blood vessels is possible, and difficulty in controlling bleeding may be very great. This is especially true in an elderly patient with arteriosclerosis. An additional incision is necessary if an adductor tenotomy is required. The approach between the adductor longus and gracilis does not represent a direct route to the exit of the nerve from the obturator foramen into the thigh, or to the extensive network of vessels usually found under the adductor longus.

In the author's experience, the anterior route is undoubtedly the simplest.

Following the first successful result and the anatomical study of the region, fifty-three patients were operated upon according to this procedure, by the author and other surgeons at the Hospital for Joint Diseases.

The cases were selected mostly for relief from pain in the presence of arthritis, irrespective of cause, and the results were considered good when pain disappeared, and when the patient could walk better after operation. The results were considered satisfactory when the pain diminished sufficiently to permit the patient to walk.

To determine the possible effect of the resection of the obturator nerve before the operation, an injection of novocain into the obturator nerve was given. The procedure of the injection is simple. The patient is placed flat on the back, and the affected extremity

is abducted to stretch the tendon of the adductor longus. A 22-gauge needle, two inches long, is then introduced near the origin of the adductor longus, close to its lateral border, and is pushed down to the horizontal ramus of the pubis. As soon as the bone is reached, the point of the needle is deflected down under the horizontal ramus and is pushed one or one and five-tenths centimeters into the foramen. Ten cubic centimeters of 1 per cent. novocain without adrenalin is injected. If relief from pain is obtained after the injection, the operative resection of the obturator nerve is considered advisable.

The following postoperative observations were made in the majority of successful cases: As soon as the patient recovered from the operation, the disappearance of pain was noticed. On the day following the operation, the patient was able to get out of bed. Examination of the extremity operated upon did not disclose any sensory disturbances over the inner aspect of the thigh or knee. In most of the cases, there was no anaesthesia and seldom any hypo-aesthesia in this area. If previous to the operation there was no severe deformity, the patient was able to walk with greater ease, as soon as the operative wound had healed. Active adduction remained normal, and was rarely even slightly weakened. But, even if preoperative flexion contractures existed, the pain was eased, and walking was more comfortable. In a certain number of cases, the pain disappeared for months, but recurred later. In cases where there was no relief immediately after this operation, patients required other surgical procedures.

Roentgenographic examination of the joints after resection of this nerve did not show any changes suggestive of trophic disturbances in the acetabulum or head of the femur, either immediately after the operation or at subsequent dates.

Of the fifty-three patients operated upon, three patients had a bilateral avulsion of the obturator nerve. The others had an avulsion in one extremity only. Ten patients had excellent early and late results. Six patients had good results. Nineteen patients improved. Seven patients showed no improvement. In eleven cases, the information was not complete. Thus, following the operation, there was improvement in over 67 per cent. of the patients in this series. Of course, it must be stated that the longest period of observation after operation was only about one and one-half years. It is impossible to foresee whether or not these patients will remain free from pain and capable of carrying on their activities.

In view of the favorable reports from France and the experiences at the Hospital for Joint Diseases, it is believed that the procedure may be of help in many instances. It is possible that, under special circumstances, it may even replace the more extensive procedures. It is not known what is responsible for the return of pain months later, in cases where relief was obtained immediately after the operation. Future experience may throw more light on this problem.

For the present, however, the operation, due to its technical simplicity and the slight amount of adduction, can be used either as an independent procedure, or in conjunction with more extensive operations to relieve or prevent pain in the hip joint.

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SALMONELLA SUIPESTIFER INFECTION OF THE KNEE JOINT

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Salmonella suipestifer, a paratyphoid organism, also known as *Salmonella choleraesuis*, gives rise to three clinical syndromes: (a) acute gastro-enteritis (it may be a cause of epidemics of "food poisoning"), (b) a typhoid-like fever due to bacteriaemia, and (c) a pyogenic infection, in which the organism becomes localized in any one of a number of sites. Cases of this condition have been reported, associated with pyarthrosis, osteomyelitis, purulent meningitis, subdural abscess, pyelonephritis, perinephric abscess, pericarditis, subacute bacterial endocarditis, peritonitis, splenic abscess, empyema of the gall bladder, acute appendicitis (a fatal case), salpingitis, infected uterine myoma, psoas abscess, periproctal abscess, and subcutaneous abscess. The infection will commonly be localized in the lung, where it gives rise to pneumonia.

Because of the absence of gastro-intestinal symptoms in some infections with this organism, and because the reputation of this organism as an abscess producer is not well known, although firmly established, it is thought worth while to report a case of infection of the knee joint with this organism.

PREVIOUS REPORTS

Harvey, in 1937, summarized the findings in seventy-one cases of *Salmonella suipestifer* infections,—fifty from the literature and twenty-one new cases. Twenty per cent. of the patients had involvement of the bones or joints. The sexes were equally affected. The individual joints were involved as follows: knee in four cases, shoulder in six cases, ankle in three cases, and multiple joints in five cases. Harvey mentions two cases with osteomyelitis, involving almost every bone in the body. In the majority of the cases of pyarthrosis and osteomyelitis, articular involvement was the first symptom of note. Only occasionally was a history of trauma to the joint elicited. The involved joint was usually swollen, warm, and tender, and aspiration revealed pus. Osteomyelitis of the adjoining bone was not infrequent. In all the fatal cases there was extensive, multiple involvement of the bones. In no case did mono-articular involvement prove fatal. Five cases of spondylitis, all in men between the ages of seventeen and forty-six, were reported. In ten cases, infection of the costal cartilage was noted,—all in men between the ages of seventeen and thirty-seven years.

Of twenty-eight cases reported by Ravitch and Washington, almost all were in negro children.

Guthrie reported a fatal case of *Salmonella suipestifer* infection in an infant, aged seven months, with pyarthrosis of the right shoulder joint. She stated that, from a survey of the literature, it appears that children are more susceptible than adults to this infection.

Gajzágó and Göttche reported six cases of osteomyelitis due to *Salmonella suipestifer*, all in children under one year of age. They also collected from the literature thirty-four cases of Salmonella infection in children under the age of two, 50 per cent. of whom had osteomyelitis or purulent arthritis.

CASE REPORT

W. M., a negro technical sergeant, was injured in a traffic accident on September 8, 1944. He suffered compound fractures of the left tibia and fibula in the middle third, and a simple fracture of the middle third

TABLE I

AGGLUTINATION REACTIONS

Date	Organism	Titer
Sept. 19, 1944	Typhoid H	1 to 320
	Typhoid O	1 to 160
	Brucella melitensis	0
Oct. 4, 1944	Paratyphoid A	1 to 40
	Paratyphoid B	0
	Paratyphoid C	0
	Organism from patient's knee fluid	1 to 320
	Organism from patient's blood	1 to 160

of the left femur. Débridement of the compound wound, manipulation of the fractures, and application of a hip spica were done at a Station Hospital on the day of the accident.

He was admitted to the 17th General Hospital on September 11, 1944. On admission, his temperature was 101.6 degrees; but, except for moderate dehydration, his condition appeared good. Inspection of his compound wound showed no evidence of infection. He was placed on a routine of 25,000 units of penicillin intramuscularly, every three hours; this was continued until October 14. His hematocrit level on September 12 was 25.4 per cent. The blood deficit was made up by repeated transfusions. He continued to have a septic type of temperature, and at times was mildly stuporous. There was daily vomiting, and he had to be given fluids intravenously. Because he gave a history of previous unexplained fever, tests for malaria were done, but no parasites were found. No reason for his fever was discovered.

By September 21, his fever had subsided, the vomiting had stopped, and his condition appeared to be good. Internal fixation of the oblique tibial fracture was done with screws, and the wound was left open. A Steinmann pin was passed through the upper portion of the tibia for treatment of the fractured femur by balanced traction. A toe-to-groin cast was applied.

His condition remained good until the night of September 25, when his fever rose to 102 degrees. He continued to have fever and, on September 28, the compound wound was explored through a window in the cast. The wound was found to be clean and, in spite of the fever, secondary closure was done. On that night, his temperature was 104 degrees, and the following day he complained of pain in the left knee. The cast was removed, and the knee was found to be warm, tender, and distended with fluid. A cloudy fluid was obtained on aspiration. The knee was irrigated with saline solution, and 10,000 units of penicillin was injected.

The patient's temperature continued to rise daily to 102 degrees. Examination of the knee on October 4 showed that it was still distended and tender. Arthrotomy was done through a medial parapatellar incision. The synovial membrane was found to be acutely inflamed. The knee was filled with purulent bloody fluid. No damage to the cartilage was seen. The knee joint was irrigated with saline solution, and the synovial membrane was closed; 10,000 units of penicillin was left in the joint. Because the patient was having so much pain in traction, he was placed in a hip spica. Reduction of the fractured femur had not been obtained with traction. On October 5, an initial dose of 4.0 grams of sulfadiazine was given, followed by 1.0 gram every four hours. On October 15, the dosage was reduced to 1.0 gram every six hours; it was discontinued on October 23.

Penicillin was again injected into the joint on October 6, through a window in the cast. By October 10, the temperature was normal. Inspection of the arthrotomy wound showed it to be clean, and secondary closure was done. There was no recurrence of fever, and the patient's general condition improved satisfactorily.

Because of this serious illness, the patient was not considered able at that time to undergo the operation required for his fractured femur. Accordingly, on November 7, he was evacuated to the Zone of the Interior in a hip spica for further care. Information is not available as to the end results in this case.

Laboratory Studies

Blood for culture was taken on September 19. After six days of incubation, an organism was grown, which was identified as *Salmonella choleraesuis*, variety Kunzendorf. Cultures of fluid aspirated from the knee on September 28, September 30, and October 2 revealed the same organism in each specimen. Subsequent blood cultures (on September 29 and October 4) showed no growth. Stool cultures on October 4 and October 7 showed no pathogenic organisms.

The agglutination reactions noted in the patient's blood are shown in Table I.

The white-blood-cell count varied from 8,150 to 13,600 cells per cubic millimeter during the febrile period of the illness, with an average polymorphonuclear count of 77 per cent. The sedimentation rate on September 24 was 17 millimeters per hour. The hematocrit rose from 25.4 per cent. on September 12 to 40.9

per cent. on October 6; repeated transfusions, totaling five liters, were given during the course of the illness. The blood sulfadiazine level on October 15 was 8.0 milligrams per 100 cubic centimeters.

Questioning of the patient regarding intestinal symptoms revealed that, on September 20, he had had diarrhoea, consisting of two loose stools; by the next day his bowels had returned to normal without treatment.

DISCUSSION

The patient received numerous forms of treatment simultaneously, and it is, therefore, difficult to decide which was effective. Neither sulfadiazine nor penicillin is supposedly effective in Salmonella infections. In this case, a combination of the two drugs, plus local therapy to the joint, was followed by recovery. It is impossible to estimate the role of the repeated transfusions or of the immunity acquired by the patient, in the subsidence of the disease.

The portal of entry is assumed to be the digestive tract. The authors' inability to culture the organism from the stool corresponds with the experience of Guthrie, who stated that the organism is rarely isolated from the faeces. In the case reported by Guthrie, the autopsy showed no intestinal lesions. Similarly, in a case reported by Boycott and McNee, the autopsy disclosed no significant intestinal lesions.

The marked trauma in the patient reported here may have favored localization of the infection to an adjacent joint. The debilitated condition of the patient may have contributed to the severity of the infection. Goulder, Kingsland, and Janeway point out that, when infection with *Salmonella suipestifer* occurs in epidemic form as acute food poisoning, the mortality is low; but when it occurs in endemic form, it often complicates some debilitating disease and has a considerable mortality.

Age is very important in the prognosis of bacteriaemia with this organism, according to Harvey. The mortality in patients less than twenty-five years of age was 19 per cent. in his series, while among patients over twenty-five years of age it rose to 58 per cent.

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SALMONELLA SUIPESTIFER PYARTHROSIS OF THE KNEE JOINT

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Infection with *Salmonella suipestifer* is unusual in man. It is not listed in Barnes's grouping [2] of the twenty-four Salmonella types found most frequently in human infections; this grouping was based upon data compiled from the National Salmonella Center, Washington, D. C.

Although paratyphoid bacilli, types A, B, and C, are generally considered the causative agents in "paratyphoid fever", almost 180 Salmonella types have been identified by serological and bacteriological means. Of these, approximately seventy-five have been recovered from human infections, and the balance from various bird and animal sources. The term salmonellosis, which includes the name of the specific etiological organism, is suggested by Barnes as a more accurate designation for the members of this group.

Bone infection results from extension of the enteric infection by way of the blood stream. The original infection may appear as (1) enteric fever, in which there is early extension of the organism into the blood stream, with such symptoms as fever, malaise, insomnia, and headache, appearing from seven to fourteen days after ingestion of the organism; (2) acute gastro-enteritis, in which a prolonged infection of the intestinal mucosa leads to late ulceration and resultant late bacteriaemia; or (3) a carrier infection, without previous gastro-intestinal symptoms. Because the majority of the salmonelloses are primarily of animal origin (occurring in domestic and wild birds, horsemeat, pork and pork products, duck, pigeon, and goose eggs, rats and mice, house flies and mosquitoes, wood ticks, and many others), human sources of infection have been largely ignored. However, Rubenstein, Feemster, and Smith isolated various Salmonella types from humans who remained infectious for periods up to six months, and even for one year after an enteric infection. Permanent human carriers are well-known sources, and are less apt to be overlooked than are persistent convalescent carriers and unrecognized cases of subclinical infection. Thus salmonellosis may spread from case to case without animal propagation.

The epidemiological and clinical implications of Salmonella infections have resulted in many contradictory reports. Because of the mild nature of some paratyphoid cases and their uncharacteristic clinical picture, which may simulate any of several common symptom-complexes, it is believed by some that these infections are inconsequential, except in infants and in the aged. Actually, persons in all age groups are susceptible to Salmonella infection, but the majority of cases do occur during the first decade of life. In Rubenstein's cases of *Salmonella typhimurium*, 39 per cent. of the patients were under ten years of age. An unusual case of *Salmonella montevideo* pyarthrosis of the knee, to be reported by Dr. Theodore H. Vinke, was also in a child.

Salmonella suipestifer or hog-cholera bacillus is usually found in association with the virus of hog cholera, but has also been isolated from cattle, sheep, and rodents, as well as from tapioca pudding, ice cream, milk, and crab meat. Human infections with *Salmonella suipestifer* have been reported from all parts of the world since it was recognized by Longcope in 1902. They frequently occur in epidemics, and are usually dietary in origin [13].

Salmonella suipestifer is a gram-negative, motile bacillus, belonging to Group C of the Kauffmann-White classification of Salmonella [6]. Jager and Lamb state that it is recognized "by its selective fermentation reactions and by agglutinations with specific antiserums". "The term '*Salmonella suipestifer*' includes several organisms that have both the somatic antigens VI and VII but differ slightly in their flagellar antigenic components and in their selective fermentation reactions." The organism is bacteriologically closely similar to Salmonella of the Oranienburg type.

Infections with *Salmonella suipestifer* in the human usually run a short but stormy course, and subside spontaneously. Numerous cases of bacteriaemia have been reported, but positive blood cultures are exceedingly difficult to obtain.

Hunter, Andresen, and Hutchinson state that the most frequent complications noted are infections of the bones and joints, purulent meningitis, endocarditis, urinary-tract infections, and secondary infections of surgical wounds. Abscess formations in other parts of the body are rare, but do occur.

Weaver and Sherwood, in 1935, reported a case of *Salmonella suipestifer* pyarthrosis of the knee joint in a nine-month-old girl. The patient had a septic course, characterized by moderate effusion and a local area of induration over the medial femoral condyle. There was roentgenographic evidence of a ragged line at the lower femoral epiphysis with spurring; elevation of the periosteum was present. At operation the periosteum was found to be ruptured just above the medial aspect of the lower femoral epiphysis; and thick yellow pus overlay the necrotic bone. The wound was drained and packed with petrolatum gauze; and the limb was immobilized in plaster, with good resulting function. Weaver and Sherwood believed that pyarthrosis due to *Salmonella suipestifer* occurred only in infants; the primary focus was in the epiphyseal plate, with extension toward the joint.

Harvey, in a comprehensive survey of fifty reported cases of *Salmonella suipestifer* infection in human beings, with the addition of twenty-one cases of his own, divided sporadic infections into two major clinical groups: The first and larger group included typhoid-like infections, characterized by bacteriaemia without localizing signs. There was usually a sudden onset, chill and fever, anorexia, vomiting, headache, rapid pulse, leukopenia, and mild bronchitis in older patients. In the second group were found infections with bacteriaemia and localization, most frequently in the pulmonary area, with resultant bronchopneumonia, lobar pneumonia, pleurisy with effusion, or empyema. Other sites of involvement were the bones and joints (in fifteen of the seventy-one cases surveyed), surgical wounds, endocardium, urinary tract, and meninges. With the localization there was suppuration and a white blood count of from 16,000 to 28,000.

Harvey noted in his cases that objective evidence of articular involvement was delayed from a few days to two months, although in the interim the patient usually complained of general malaise and had difficulty in using the affected extremity. A history of trauma was occasionally elicited. The patient usually had a remittent fever, but was sometimes afebrile. Examination revealed a warm, swollen, tender joint with erythematous skin and pain on active and passive motion. Effusion was almost always present. Greenish purulent material was obtained on aspiration; culture yielded pure *Salmonella suipestifer*. Osteomyelitis of adjacent bones was frequently found. Roentgenographic findings were often normal in the early stages, but later such changes as periosteal thickening, rarefaction, and erosion of the adjoining bone were seen.

Harvey listed four cases involving the sacro-iliac joint, ten with infection of the costal cartilage, two of the sternoclavicular joint, three of the hip joint, two of the knee joint, and one of the symphysis pubis,—a definite predilection for the amphiarthroidal type of joint. Except for one ten-year-old girl, all of the patients were men, ranging in age from seventeen to thirty-seven years. Treatment by repeated aspiration or open drainage of the joint, and traction or immobilization as indicated, usually resulted in rapid fall of the temperature to normal, gradual subsiding of the swelling, and free joint motion in from three to six weeks, with resultant complete function.

Ssokoloff mentions thirty cases of surgical complications, including five cases of spondylitis; his patients were men, ranging from seventeen to forty-six years of age.

The following case of *Salmonella suipestifer* pyarthrosis of the knee joint is of unusual interest, because of a pre-existing osteochondritis dissecans of the femoral intercondylar notch, which may well have been a factor in the localization of the infection.

CASE REPORT

E. T. (Cincinnati General Hospital No. 214428) was a single negro male, thirty-eight years old. He was admitted June 3, 1946, with a chief complaint of pain in his left knee (Fig. 1-A). Ten days before admission, he tripped and struck his left knee on the sidewalk; this was followed by pain of several hours' duration. After the pain had disappeared, he was able to return to work. The day before admission he awoke with sharp pain in his left knee, despite which he was able to get around. The knee was quite warm, but not swollen. That night his knee became swollen and warmer; he felt feverish; and he was unable to bear weight on the knee.

There was no history of familial disease or of tuberculous contacts. The past history revealed that, eleven years before, his left knee had been struck by a baseball bat. The injury produced pain and swelling which were treated by limited weight-bearing for four months. Following this episode the knee always seemed larger than the right one, and the patient had intermittent periods of pain and swelling after minor traumata. Two years before admission he fell, while working at an airplane plant, and injured his knee once more; thereafter, pain and discomfort became more frequent and more intense. He had been given a medical discharge from the Army eight months before onset of his present difficulty, because of recurrent effusions, requiring aspiration, and limited function of his left knee after a fall from a motorcycle. His service had been largely in the Midwest, and he had not left the United States. He denied any venereal disease or urethral discharge. There had been no ingestion of uncooked meats or unpasteurized milk, and no dietary indiscretions.

On admission, the patient's temperature was 101.6 degrees, pulse 68 and respirations 22 per minute. The blood pressure was 130 systolic and 76 diastolic. Physical examination showed a well-developed, well-nourished negro male in moderate distress, lying on his right side. Positive findings were limited to the left knee, which was swollen, hot, and exquisitely tender over the entire joint area; moderate effusion was present. The knee was held in 175 degrees of extension; attempted flexion was painful and was limited by muscle spasm.

The blood findings on admission were as follows:

Red blood cells	5,750,000
Hemoglobin	12 grams per 100 cubic centimeters
White blood cells	8,450
Polymorphonuclear neutrophils	65 per cent.
Lymphocytes	33 per cent.
Monocytes	2 per cent.

The urine contained a trace of albumin and from ten to twenty white blood cells per high-power field. Urethral and prostatic smears were negative for gram-negative intracellular diplococci. The blood Kahn reaction was negative. The blood urea nitrogen was 14 milligrams per 100 cubic centimeters. An electrocardiogram revealed nothing abnormal.

Aspiration of the knee-joint fluid was performed in the receiving ward, and 65 cubic centimeters of amber cloudy fluid, filled with pus cells, was sent to the laboratory for culture and analysis.

Roentgenograms of the chest were negative. Roentgenograms of the left knee revealed osteochondritis dissecans of the intercondylar notch of the femur, and swelling of the joint capsule.

Sulfadiazine, an initial dose of two grams and then one gram every four hours, was instituted on the day of admission, following a presumptive diagnosis of gonococcal arthritis; but the temperature rose to 103.6 degrees, despite maintenance of adequate blood levels. Penicillin, 20,000 units intramuscularly every three hours, was, therefore, added the following day. On the second day of the patient's stay in the Hospital, 65 cubic centimeters of a yellow, turbid, viscid fluid was aspirated from the joint. Microscopic analysis disclosed 17,500 white blood cells with 88 per cent. polymorphonuclears, and 4,125 milligrams of protein per 100 cubic centimeters. Direct smears were negative, including acid-fast stains. The fluid was sent to the central laboratory for culture. The dosage of penicillin was increased to 25,000 units every two hours, but the knee remained hot, tender, and swollen, and the high fever continued.

Blood cultures were taken on the patient's second and fourth days in the Hospital; they were reported as negative.

Daily aspirations of the joint fluid were performed; the purulent and high-protein character of the fluid remained essentially the same. On the fourth day in the Hospital, the first culture of the knee-joint fluid was reported to contain an unidentified gram-negative bacillus. Further laboratory studies were instituted, including a blood Widal test for typhoid and paratyphoid, A and B, brucellar agglutinations, and a complement-fixation test of the blood for gonococcus. All of these tests were negative. On the tenth hospital day the organism, found in the aspirated fluid on admission, was identified positively by fermentation and serological reactions as *Salmonella suipestifer* (Kunzendorf variety). This was confirmed by reports of positive cultures in each of the nine daily aspirations of the knee-joint fluid, performed subsequently. Stool cultures were negative for pathogenic organisms. In view of the finding of a gram-negative bacillus, and the lack of response to previous therapy, the sulfadiazine and penicillin were discontinued, and streptomycin therapy was begun (on the seventh hospital day).

FIG. 1-A

FIG. 1-B

Note the lesion of osteochondritis dissecans in the posteromedial portion of the medial femoral condyle in both roentgenograms. There is also an appreciable widening of the interarticular space, and minimum hypertrophic lipping of the medial tibial tuberosity in the anteroposterior view.

The intramuscular administration of 125 milligrams of streptomycin in 3 cubic centimeters of saline every three hours resulted in a rapid fall in temperature, and in negative joint and blood cultures. However, the streptomycin had to be discontinued after nine days, because of repeated sterile abscesses at the sites of injection.* Two days later the joint fluid again gave a positive culture for *Salmonella suipestifer*, and additional streptomycin was given by the intravenous route; this form of administration, too, had to be discontinued, because of a severe febrile reaction and local thrombophlebitis. The temperature dropped to normal by lysis on the twenty-sixth hospital day, and remained normal thereafter (Fig. 1-B).

The fluid in the knee again required aspiration on July 7 (the thirty-fourth hospital day), at which time cultures for *Salmonella suipestifer* were still negative; however, there were 7,800 white blood cells per cubic millimeter. Blood agglutinations, taken at this time for paratyphoid B, were positive up to dilutions of 1 to 320. The knee improved progressively, so that, on the forty-second hospital day, it was no longer swollen or tender. Motion was still restricted, however, from 180 degrees of extension to 105 degrees of flexion. There was still some synovial thickening, but no effusion. Physiotherapy was begun cautiously, and resulted in an increased range of motion. The patient was discharged from the Hospital on July 26, the fifty-second hospital day, on crutches without weight-bearing.

He failed to appear for his physiotherapy appointments, and when next seen in the Orthopaedic Clinic, on August 2, two months after his original admission, there had been some regression in joint motion, the range then being from 180 to 130 degrees. The patient had discarded his crutches of his own accord. When seen two weeks later, there was some residual thickening of the left knee, which was three-quarters of an inch larger in circumference than the right knee, and the range of motion was from 175 to 100 degrees. Slight tenderness was noted on the anteromedial aspect of the joint. A culture, secured by saline lavage of the joint, was reported as negative. The patient was last seen on August 30, at which time there was no swelling or tenderness, no synovial thickening, and no instability. He had a range of motion from 180 to 90 degrees, and he was able to resume his occupation as a tire worker.

* A report on streptomycin, to be published by the Department of Medicine, will include further details of the streptomycin therapy and its complications.

COMMENT

The presence of a degenerative joint lesion, osteochondritis dissecans, which had been aggravated by repeated traumata, may have predisposed the joint to localization of the infection. However, it apparently did not influence the course of the infection, since complete recovery occurred in three months from the time of onset, without extension of the suppurative process into the adjoining bones. This might have been expected from the loss of the normal cartilaginous barrier in the region of the osteochondritic defect. The defect showed no roentgenographic change during the course of the infection.

Only a few cases of typhoid and Salmonella infections have been treated by streptomycin. Results were reported as generally unsatisfactory [7]. In this case, clinical improvement (fall of temperature and pulse to nearly normal and decreased swelling and pain in the knee) was manifest three days after streptomycin therapy was begun. The positive joint cultures became negative and remained so, when sufficient streptomycin had been given.

Although the infection resolved completely, and the immediate functional result was excellent, it is to be expected that the degenerative changes of osteochondritis dissecans, previously present, will result in more joint disturbance at a later date. An arthrotomy may be required, but this will be delayed until it is deemed safe to open the joint.

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FRACTURE OF THE FEMORAL SHAFT COMPLICATED BY HIP DISLOCATION

A Method of Treatment

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Traumatic dislocation of the hip is a relatively rare injury, comprising about 2 to 5 per cent. of all dislocations. Dislocation of the femoral head, complicated by a fracture of the femoral shaft, is an extremely rare lesion which always presents a problem of treatment. Such a case is reported here because of the method of treatment which, as far as the authors are aware, has not been described previously.

John Royal Moore classified fracture-dislocation of the hip as follows:

1. "Central dislocation of the femoral head.

2. "Posterior dislocation of the femoral head accompanied by fracture of the acetabular rim.

3. "Posterior dislocation of the acetabulum accompanied by fracture of the femoral head."

To this classification, we must add two types less frequently seen:

4. Dislocation of the hip with fracture of the neck of the femur, as described and treated by Hart and Watson-Jones with Whitman reconstruction operations.

5. Dislocation of the hip, accompanied by a fracture of the shaft of the femur.

The last type is found less frequently than the first four, and it is in this last classification that the case reported here belongs. In reviewing the literature, we find only scanty mention of this type of injury, although we feel sure that many of these injuries occur in this automotive age and go unreported.

In 1934, Henry and Bayumi reported one case of dislocation of the hip with fracture of the shaft of the femur among 9,945 cases of fractures and dislocations, treated over an eight-year period in a Cairo hospital, or approximately one case in 10,000. They reviewed the literature and found fifteen other cases, most of which had occurred in the nineteenth century; the first one was reported by Sir Ashley Cooper, in 1823. Over a period of thirty-one years at Henry Ford Hospital, four cases have been seen in a total of 496,700 patients. This would be about one case in 125,000.

King and Richards, in their very complete article on fracture-dislocations of the hip joint, mentioned this condition as one of the five indications for open reduction. They stated that they had treated one patient with dislocation of the hip and fracture of the femoral shaft, and had observed two others. Watson-Jones referred to this type of fracture-dislocation of the hip by saying: "Sixteen cases have been recorded . . ." These were probably the sixteen cases mentioned by Henry and Bayumi in 1934. Watson-Jones advocates open reduction, if manipulative reduction fails. Key and Conwell also discussed this as a rare type of injury, and suggested the same treatment as that advocated by Watson-Jones. Hammond commented: "Dislocations complicated by fractures of the shaft of the femur often necessitate open reduction".

Of the authors' four cases, open reduction of the dislocation of the hip was required in three. We were able to reduce the dislocation in the case described here by closed reduction with the method mentioned, in spite of the patient's strong musculature.

CASE REPORT

M. O. (Case No. 471057) was a white male, thirty-five years old, who, while welding at the Ford Motor Company on March 25, 1946, was struck from behind, when kneeling, by a large girder which had slipped

from an overhead crane. This girder struck the patient over the posterolateral aspect of the left thigh, knocking him to the ground. The patient stated that he felt a crumbling of bones in his left lower extremity, had severe pain, and was unable to get up. One hour later, when the patient was examined at the Hospital, he was in mild surgical shock and had a dirty six-inch transverse laceration of the supracondylar area of the femur, a large hematoma over the left gluteal region, and a gross deformity with angulation of the upper third of the left thigh. There was inability to extend the proximal fragment and, therefore, a marked bowing at the juncture of the middle and upper thirds of the left femur. Roentgenograms disclosed an oblique fracture of the upper third of the left femur, and a complete posterior dislocation of the hip joint (Fig. 1).

The patient was treated for his mild shock with fresh whole blood; then the wound of the supracondylar area was irrigated, debrided, and closed under general anaesthesia. Following this, an unsuccessful attempt at closed reduction of the dislocated hip was made with the Bigelow and Allis procedure. Thereafter, a reduction-retention apparatus with threaded pins was used, with the pins placed approximately four inches apart into the lateral aspect of the trochanter of the left femur (Fig. 2). Another attempt at closed reduction was made, the pins being used in an effort to control the proximal fragment; but, because of this patient's musculature and marked muscle spasm, this attempt also was unsuccessful. A Kirschner wire was placed through the area of the tibial tubercle; the patient was sent to the ward and placed in traction, with twenty-five pounds of weight on the Kirschner wire and another twenty-five pounds of weight on the reduction apparatus.

On March 28, three days after the injury, another unsuccessful attempt at closed reduction was made; the reduction apparatus was used to control the proximal fragment. Following this, a two-foot length of gas pipe was threaded over the crossbar of the reduction apparatus (Fig. 3), thus paralleling the distal fragment and being attached through the apparatus to the proximal fragment. With the gas-pipe lever, a successful reduction was carried out, by means of the Bigelow manoeuvre. The patient was then returned to the ward, where he was placed in skeletal traction. Roentgenograms, taken the next day, showed the head of the femur to be in the acetabulum and the fracture to be in almost anatomical position and excellent alignment (Fig. 4).

On June 29, approximately three months later, the patient was put in a plaster hip spica. This was maintained until the first week in September 1946, when it was found, after testing the patient clinically and taking roentgenograms, that he had non-union at the fracture site and that the proximal fragment of the femur cast a shadow of increased density (Fig. 5-A). It was thought at that time that the increased density of the proximal fragment was due to massive stripping of the periosteum at the time of the original injury, since the proximal fragment had been considerably displaced because of the dislocation of the hip. The patient's skin

FIG. 1

FIG. 2

Fig. 1: March 25, 1946. Roentgenogram, taken the day of the accident, shows posterior dislocation of hip and fracture of shaft of femur.

Fig. 2: March 29, 1946. Shows reduction-retention apparatus in place, with threaded pins extending into trochanteric region of femur. Dislocation of hip has been reduced.

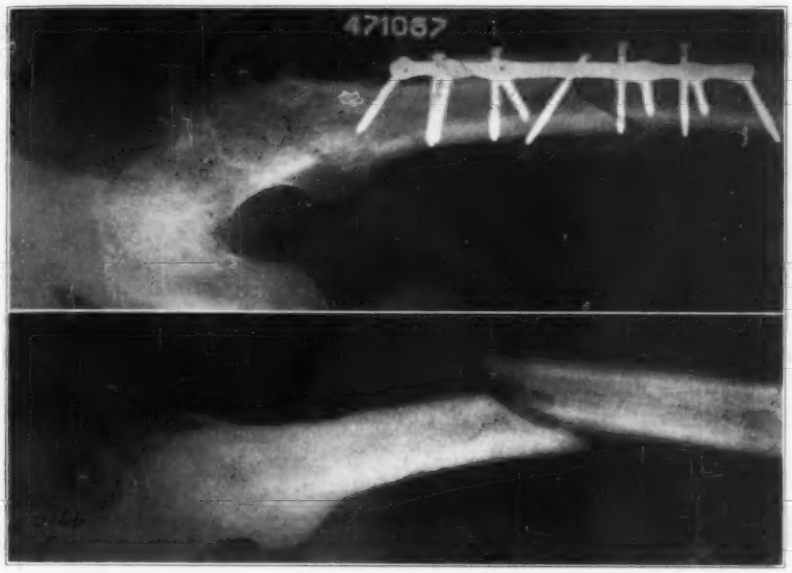

FIG. 5-A FIG. 5-B

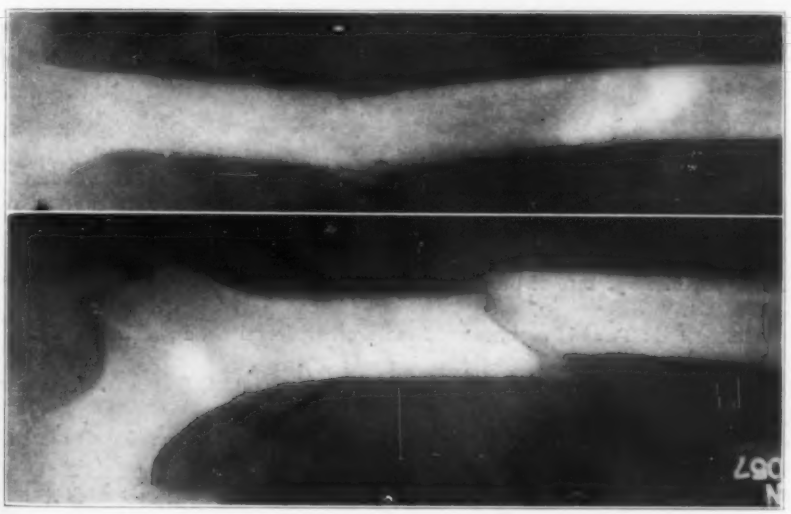

FIG. 4

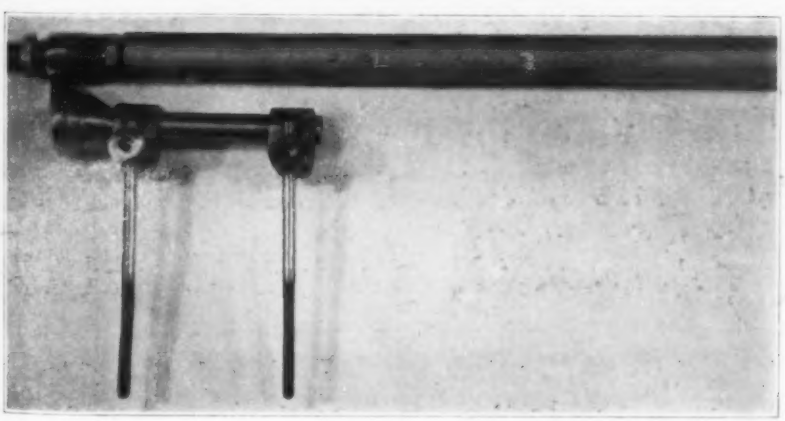

FIG. 3

Fig. 3: Photograph of threaded-pin apparatus, with two-foot piece of gas pipe attached.
Fig. 4: April 11, 1946. Pins of the reduction apparatus have been removed and the patient has been placed in skeletal traction.
Fig. 5-A: September 9, 1946. Roentgenogram, taken six months after reduction, shows sclerosis of proximal fragment of femur and non-union of fracture.
Fig. 5-B: December 31, 1946. Twelve weeks after open reduction and tibial onlay bone graft. There is no evidence of aseptic necrosis of the head of the femur.

was prepared for surgery during the last two weeks of September. On September 30, 1946, an open reduction was performed; and a Vitallium plate and massive onlay bone graft from the tibia were placed across the fracture site. The postoperative course was uneventful, and the patient remained in the hip spica until December 31, when it was found by clinical and roentgenographic examination (Fig. 5-B) that he had solid bony union. Since that date he has received physiotherapy to the hip, knee, and ankle, and has been walking with a double upright, non-weight-bearing brace.

At present the patient has considerable limitation of flexion of the knee; he can flex the hip to 90 degrees, although there is still rather marked limitation of internal and external rotation of the hip joint. To date there has been no evidence of aseptic necrosis of the head of the femur.

CONCLUSIONS

Dislocation of the hip, complicated by a fracture of the shaft of the femur, is an exceedingly rare condition and presents a most difficult problem in reduction. It is a well-known fact that this type of injury occurs in young and middle-aged adults most frequently, and is caused by only the most violent forms of trauma. For this reason, it is usually seen in a very muscular type of patient, which makes closed reduction even more difficult.

The problem in reduction arises from the fact that the lever arm, the femur, is not intact and one has no control over the proximal fragment. The authors were able to restore the lever arm by means of the gas-pipe extension on the pin-fixation apparatus, and thus were successful in the reduction.

The authors feel that non-union developed because of the excessive stripping of the periosteum from the proximal fragment, caused by the marked displacement resulting from the dislocation of the hip. The increase in density of the proximal portion of the shaft of the femur, probably due to the damage to the blood supply secondary to the periosteal stripping, is shown in Figure 5-A.

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THE TREATMENT OF DROPPED SHOULDER

A New Operative Technique

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Paralysis of all shoulder muscles is apt to affect seriously the function of the shoulder girdle. The characteristic features of this condition are:

1. Distal and ventral sliding of the scapula.
2. Winging of the scapula (scapula alata).
3. Abolished function of the posterior cervical muscles, causing a forward inclination of the head.
4. The weight of the arm, no longer subject to muscle control, draws the head to the paralyzed side.

The object of therapy is twofold: (1) fixation of the scapula to the thorax, and (2) correction of the pathological posture of the head.

Plastic operations, as devised by Henry, Whitman, Dickson, and Dorling, consist essentially in the construction of fascial slings, leading from the scapula to the muscles and the spinous processes of various thoracic vertebrae. These methods are chiefly used in cases of unopposed action of the serratus. Hence, they are dealing merely with one of the pathological components in question. Dickson described a method for lifting a drooping shoulder after paralysis by the use of two fascial slings, leading separately from the spine of the scapula to the cervical muscles and the spinous process of the first thoracic vertebra. Nothing, however, is known of the late end results following this method.

Every operation which consists in transplantation of fascia is likely to yield satisfactory results, if the transplanted fascia is actually converted into solid scar tissue. It is, however, still doubtful if these strong bands are able to carry the weight of the arm permanently, without the assistance of the muscles.

In two particularly difficult cases of paralysis of the shoulder after anterior poliomyelitis, our procedure was totally different. The method employed consisted essentially in fixing the scapula to one of the ribs. Three different methods were used, as one of the patients had to be operated upon twice.

CASE REPORTS

Case 1. The patient, a boy fourteen years of age, was admitted to the Hospital on March 27, 1942. Five days previously he had been taken ill with acute poliomyelitis. During the first two days of his hospital stay, paralysis spread to all four extremities and to the trunk. On the third day, respiration became difficult; and he was placed in the "iron lung", where he was left for six days. At the end of that time his condition had improved so much that normal respiration took place. The paralysis of the lower extremities and hands subsided slowly. When he was discharged, in June 1942, he still presented extensive paralysis of both shoulders,—namely, in the deltoid, supraspinatus, infraspinatus, and trapezius muscles. On the right, there was still a trace of function in the superior part of the trapezius, the posterior cervical muscles, and the serratus anterior.

In spite of intensive exercise and fixation of both shoulders, a high thoracic scoliosis developed, with its convexity to the right. The patient found it particularly embarrassing that his chin was lying on his chest and that he was unable to raise his head. The right shoulder dropped more and more. In order to look around, the patient had to hold his lumbar spine in exaggerated lordosis, which interfered seriously with normal walking. He suffered, moreover, from severe headaches when walking, probably caused by the abnormal posture of his head (Figs. 1-C and 1-D).

Our first object was to fix the drooping shoulder girdle and then to replace the elevators of the head by fascial transplantation.

First Operation (May 25, 1943)

Under general anaesthesia, the lower edge of the right scapula and the fifth and sixth ribs were exposed subperiosteally. The fifth rib was resected to a length of six centimeters. In the distal end of the scapula (angulus inferior) two holes were bored, and through each of them a length of wire was passed. The distal end of the scapula was slipped through the defect, created by the resection of the fifth rib, and was placed behind the sixth rib, to which it was fixed by the two wire loops (Fig. 1-A). The wound was closed and the arm was fixed to the chest by a Velpeau bandage.

Roentgenographic follow-up after ten days showed that the wires had become loose, so we assumed that the fixation of the scapula would be inadequate and decided to operate again.

Second Operation (June 13, 1943)

Under general anaesthesia, the distal end of the scapula and the sixth rib were exposed. The wire had cut through the scapula on one side, while on the other it had become loose. It did not seem advisable to try the same method of fixation again, so we proceeded as follows: The distal end of the scapula was split along its long axis to a length of two centimeters. The two jaws were placed on the sixth rib, the scapula, as it were, riding on the rib (Fig. 1-B). The wound was closed and the arm was placed in a Velpeau bandage for five weeks. After the bandage had been removed, the scapula proved to be firmly attached to the rib.

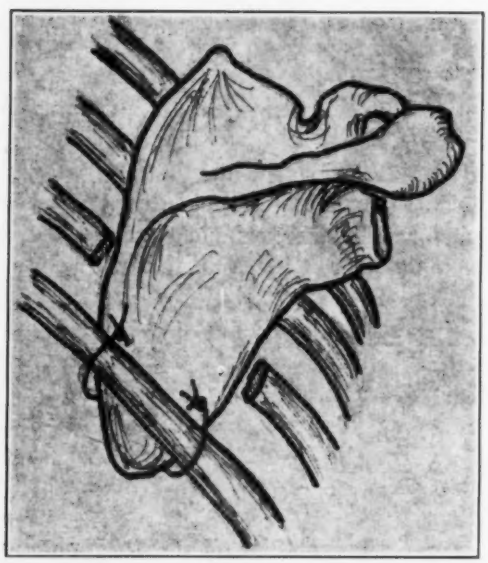

FIG. 1-A

Fig. 1-A: Shows resection of fifth rib and attachment of scapula to sixth rib by wire loops.

FIG. 1-B

Fig. 1-B: In the second operation, the scapula was split so that it rests on the sixth rib.

FIG. 1-C FIG. 1-D

Case 1. Photographs taken before operation.

FIG. 1-E FIG. 1-F

Photographs taken in 1945.

Follow-up Examination (October 1945)

The shoulders were at the same level on both sides. The head was carried free and straight. Only the upper portion of the trapezius on each side was rated fair and participated in the raising of the head. Otherwise, there was no change in the muscle state (Figs. 1-E and 1-F). The right arm could be abducted passively to 90 degrees; this was accompanied by an upward movement of the clavicle. This fact is particularly important as it indicates that, in spite of extensive fixation of the scapula to the rib, the "pseudo-articulation" between the scapula and the rib allows a certain amount of movement.

For the past year the boy, now eighteen years old, has been working in a glass-cutting and optical workshop. The headaches, which had been a great nuisance prior to the operation, have disappeared. Abduction of the arms is still impossible, but he is able to look after himself without any help.

CASE 2. The patient, a man twenty years of age, was admitted to the Hospital on June 27, 1942. Three days before, acute poliomyelitis had developed. On admission, he presented paralysis of both arms and paresis of both legs, as well as disturbed deglutition. When he was discharged, in September 1942, he still presented paralysis of the left deltoid, the upper part of the trapezius, and all the shoulder muscles on the right.

A high thoracic scoliosis developed, with its convexity to the right. The right shoulder was lower than the left one, and the vertebral edge of the scapula winged distinctly (scapula alata). The chin was resting on the chest and the head was inclined toward the right side. Lifting of the head was possible only by bending the trunk backward and relaxing, as far as possible, the sternomastoid muscles.

FIG. 2-A

Operative procedure carried out in Case 2. The rib has been passed through a hole bored in the scapula.

FIG. 2–B

FIG. 2–C

Roentgenograms show fixation of scapula to rib.

In view of our experience in the preceding case, another method of fixation was tried.

Operation (May 8, 1944)

Under local anaesthesia, the lower part of the right scapula and the sixth rib were exposed subperiosteally. The rib was cut at the level of the posterior axillary fold. The dorsal portion was grasped by pliers, crushed, and bent upward. Into the lower angle of the scapula, a hole was bored of a diameter of approximately two centimeters, through which the rib was passed in such a way that the vertebral edge of the scapula was covered by the rib dorsally. The two ends of the rib were approximated and fixed loosely to each other by bone suture (Fig. 2-A). The intercostal nerves were blocked by a 1 per cent. novocain solution. A Velpeau cast was applied, and worn for four weeks.

When the cast was removed, it was found that bone healing had taken place at the site of resection, and that the scapula was immovably fixed to the rib (Figs. 2-B and 2-C).

Follow-up Examination (November 1945)

The shoulders were at the same level on both sides, and the head was carried free without any effort. Active elevation of the head was performed by the posterior cervical muscles with fair strength. The function of these muscles before the operation could not be traced. The right scapula was absolutely immovably fixed to the rib. Although there was still paralysis of the deltoid muscle, the right arm could be moved more freely than prior to the operation. After his operation the patient, who lived in an agricultural communal settlement, was again fit for physical work.

COMMENT

An attempt was made to improve conditions of extensive paralysis of the shoulder muscles, by three different operations.

The first, consisting in fixation of the scapula by wire, proved a failure. Whether this was due to an inadequate technique or to insufficient immobilization after the operation is difficult to decide. Of the three methods tried, this was the least satisfactory, since foreign material introduced into the tissues in the neighborhood of the pleura will always give rise to complications.

The second method, consisting in splitting the scapula and making it "ride" on the rib, has the advantage that, after perfect fixation has been established and the position of the scapula has been rectified, a certain amount of movement is still possible between the scapula and the chest wall. It will probably have to be decided for each case individually, whether or not resection of the fifth rib is really necessary in order to attach the scapula alata to the chest. Of special advantage is the "pseudarthrosis" between scapula and thorax, in view of the fact that the mobility of the shoulder girdle depends upon the mobility of all the individual parts of this complex. This method of fixation of the scapula might possibly be used advantageously as a preliminary act for plastic operations on the paralyzed deltoid muscle. After the transplantation, part of the initial success is often lost, owing to the inability of the transplanted muscles to carry the weight of the arm and to restore its function. By this second operation, the first object is achieved and the transplanted muscle may now serve exclusively to improve function.

The third method, by which the rib is passed through the scapula, effects the most secure and solid union. It has, however, the disadvantage that movement between the scapula and the thorax is completely and permanently destroyed. This type of fixation should be confined to cases in which muscle transplantation is impossible, owing to lack of material.

The author's reconstruction included a second stage, consisting in correction of the abnormal posture of the head. In both cases, however, it could have been omitted, since in each the head could be moved and held straight without effort after the operation, although in one case the upper portions of the trapezius muscles were only fair and in the second case the posterior cervical muscles were only fair. This would suggest that the main reason for the abnormal posture of the head is a shift of balance within the shoulder girdle; and, as soon as this has been rectified, the head can be balanced normally on the trunk without considerable active effort.

NOTE: The author wishes to express his sincere thanks to Dr. K. Friedman, the thoracic surgeon of the Beilinson Hospital, for his active cooperation in the performance of the operations.

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A DEPTH GAUGE FOR BONE SURGERY

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A simple depth gauge has been designed to ensure, easily and quickly, the proper length of screws in bone surgery. The instrument of this type most often seen in general use consists of a slim steel bar with a hook or right angle on the distal end. Upon this rod is mounted a sliding metal collar with a set screw to fix it firmly to the rod at the desired place. This device has certain drawbacks, the most important of which is that the set screw must be screwed in firmly or not at all. When the instrument has been passed through the screw hole, the bent end engaged in the opposite cortex, and the sliding collar pushed against the proximal cortex, the set screw must be engaged firmly. This manoeuvre often prevents the disengagement of the instrument and its withdrawal from the drill hole. It is necessary then to loosen the set screw, and an error is introduced when the sliding collar backs away from the bone.

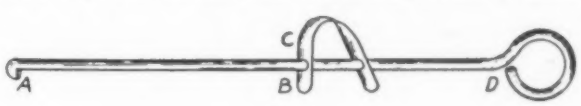

FIG. 1

The instrument described here (Fig. 1) is designed to overcome these difficulties. It consists of a stainless-steel rod, one-sixteenth of an inch in diameter, with a right-angled end (*A*), two thirty-seconds of an inch long. The rod is six inches long from the tip to the proximal end, which is bent into a ring. It was felt that a ring handle would be superior to increasing the caliber of the rod at the proximal end (*D*), and thus increasing the likelihood of bending the thin distal segment when the gauge was in use.

Upon this rod is a sliding spring of stainless steel (*C*). This spring is so bent that it can be moved toward the distal end of the rod by pressure on the arm closer to the ring, but it will not slide back toward the handle unless both members are squeezed together.

To use the instrument, the distal end is passed through the drill hole until the right angle can be engaged on the opposite cortex. The spring is then slid up against the bone. It remains there by its own tension. By a slight twisting motion, the hook can be disengaged without the spring backing up more than a tiny fraction of an inch. The proper length of screw is then determined by direct comparison.

OLECRANON FRACTURES

A Method of Wiring

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During the past seven years at the United States Marine Hospital, a method of wiring the fragments in fracture of the olecranon has been devised, in which a 22-gauge steel wire has been used for fixation and immobilization of the approximated bone fragments. This procedure has permitted motion in two to three weeks, without danger of separation of the fragments at the fracture site; possible buckling of the bone fragments, anteriorly, posteriorly, or laterally; or axial rotation.

Open reduction is indicated when there has been a fracture of the olecranon with separation or angulation of the fragments, producing a disturbance of the concavity of the semilunar notch. The procedure to be described has also been used in conjunction with the preliminary fixation of fractures of the olecranon, when they have been associated with fractures or dislocations of the radius or with fractures of the condyles of the humerus.

A posterior elliptical incision is made in the region of the elbow. The olecranon is exposed by blunt dissection. The anconeus and supinator on the lateral aspect of the

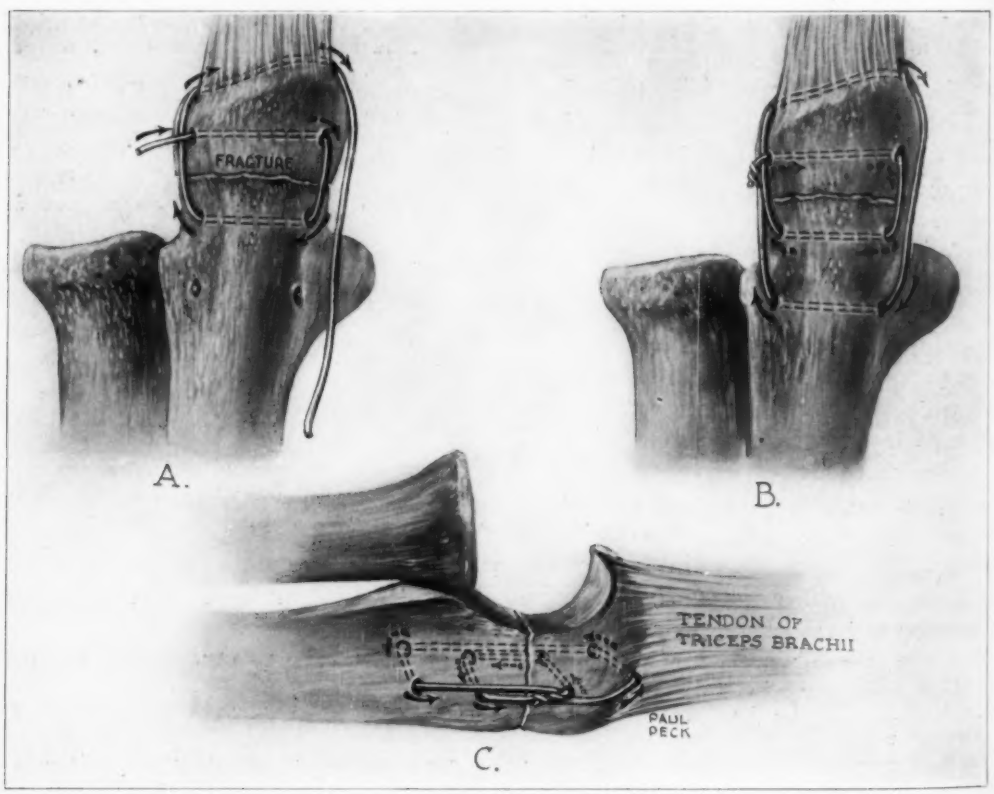

FIG. 1

Wiring of olecranon. *A:* Passage of 22-gauge stainless-steel wire through drill holes near fracture site. *B:* Twisting and fixation of wire loop. *C:* Lateral view, showing position of drill holes and direction in which wire is threaded.

olecranon are dissected from the bone, as is the flexor digitorum profundus, for a distance of approximately one inch distal to the site of fracture. By a No. 1 drill, two holes are placed through the bone transversely (slightly eccentric to the mid-shaft) one-quarter of an inch above and below the fracture line. In cases of comminution, the main fragments are drilled. Another drill hole is placed transversely, a thumb's breadth below and parallel with the primary drill hole on the distal fragment.

Beginning on the radial border of the proximal fragment, a 22-gauge stainless-steel wire is threaded through the drill hole (Fig. 1,*A*) and then in a circle through the proximal drill hole on the distal fragment. The wire is continued through the site of attachment of the triceps tendon to the olecranon at the same depth as the drill holes. It is then threaded through the lower drill hole of the distal fragment and looped with the wire at the starting point. The anterior surface of the semilunar notch is examined by the surgeon to make certain that, with tension on the wires, the fragments are fixed in a position of anatomical reduction. As soon as the position is judged to be satisfactory, the assistant makes the wires taut by means of two clamps; several twists are then made in the wire ends. The ends of the twisted wire are cut, so that approximately one-third of an inch remains; they are bent over on themselves anteriorly and buried subperiosteally. The wound is closed in layers with interrupted sutures, and a posterior plaster splint is applied from the axilla to the metacarpophalangeal joints. Passive motion is begun in approximately two weeks, if the fracture consists of two fragments; and in three weeks if it is comminuted. Whirlpool-bath treatments, combined with active and passive motion, are carried out before the end of one month. Full motion is usually restored before the sixth or seventh week of treatment.

Twelve cases have been treated during the past seven years, with a follow-up observation period of approximately six to seven years. A complete restoration of function and stability was obtained in eight cases; in four cases, a slight residual defect of flexion and extension occurred, which was explained by the extent of comminution at the time of the fracture and by some narrowing of the semilunar notch. Bony union was obtained in each case. In one instance, it was necessary to remove the wire at the end of six months, since the loop was not turned under the periosteum and the wire produced an area of irritation during flexion and extension.

Sensory Denervation of the Heel for Persistent Pain Following Fractures of the Calcaneus

(*Continued from page 212*)

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A UTILITY ATTACHMENT FOR CINEPLASTIC ARTIFICIAL ARMS

BY HENRY H. KESSLER,* M.D., NEWARK, NEW JERSEY

The device described here is an attachment designed to increase the usefulness of cineplastic artificial arms. In cineplasty, the muscles which remain in the amputation stump are used as a motive force to operate the artificial hand. Canals are made in the flexor and extensor muscle groups in the forearm, and in the biceps and triceps muscles in the upper arm. Pegs are inserted through these canals and are attached to stirrups which act directly, through a system of mechanical levers, to open and close the artificial hand. The idea was originally suggested by Vanghetti, and was developed by Putti, Sauerbruch, and others.

The operation of the cineplastic hand by means of cineplastic muscle motors has always had a limited application to the needs of factory workers, farmers and laborers, and others who require a prosthesis which can provide considerable power. It has a distinct advantage, however, because of its automatic and effortless control and, in the case of a forearm prosthesis, because of the avoidance of straps and a shoulder harness. It has been hoped that the prosthesis could be adapted to heavier physical demands.

Many efforts have been made to devise work arms, cineplastically controlled, but without much success. Galeazzi developed an apparatus which was essentially a work tool, attached to cineplastic motors in such a way as to change the position of the work tool, but not to open or close it.

The attachment presented here is one in which the work tool or forceps is directly controlled by the cineplastic motors, so that it is opened or closed automatically (Fig. 1). A system of mechanical levers, acting directly on the arms of the forceps, are connected to the pegs which run through the cineplastic motors. Movement of the muscle motors thus opens or closes the utility attachment with selective pressure to exercise minute and precise force, sufficient to hold objects without crushing them (Fig. 2). This is a function which is not well performed by the standard utility hook, operated by means of a lanyard attached

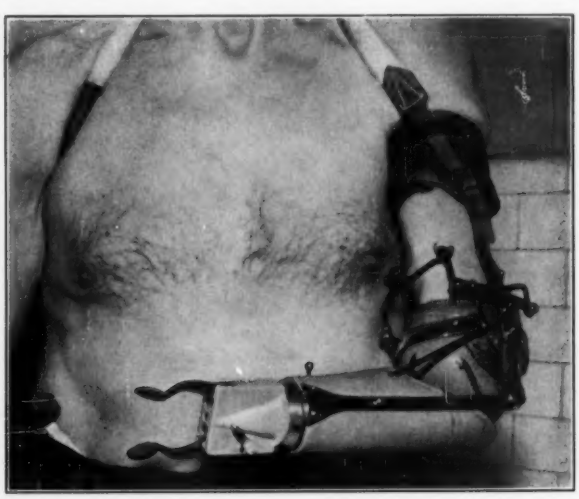

FIG. 1

FIG. 2

Fig. 1: Cineplastic prosthesis with utility attachment. (Reproduced, by permission of Charles C. Thomas, from *Cineplasty* by H. H. Kessler.)

Fig. 2: Selective pressure exerted by cineplastic motors on utility attachment permits grasp of object without crushing it.

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FIG. 3

FIG. 4

Fig. 3: Utility attachment with lock device (*a*).
Fig. 4: Interchangeable couplings of cineplastic hand and utility attachment. (Reproduced, by permission of Charles C. Thomas, from *Cineplasty* by H. H. Kessler.)

to a loop passing around the opposite shoulder. When the lanyard is relaxed, the hook snaps shut, due to the spring action of the rubber band fixed to the base of the hook. Thus a small object would be crushed because of the operator's inability to select the exact amount of pressure.

The utility attachment permits the patient with a cineplastic prosthesis to perform work requiring heavier physical demands. The attachment is opened and closed automatically for operations requiring rapid grasp and release. For long-continued holding, the attachment is equipped with a lock device which permits work, without fatigue to the cineplastic motors (Fig. 3).

Another feature of this device is that it can be interchanged with a cineplastic hand. This is accomplished by a special spring coupling which permits the use of the same system of levers for the operation of the hand or forceps (Fig. 4). The utility attachment thus provides a device for heavy work, while the hand permits light activities and satisfies the need for a dress appliance.

CAST TREATMENT OF ACROMIOCLAVICULAR DISLOCATIONS

BY GORDON MONROE MORRISON, M.D., SAN MATEO, CALIFORNIA

A recent comprehensive article on the subject of dislocations of the acromioclavicular joint by Urist [1] includes a bibliography of 101 references. Such a plethora of articles about a relatively simple lesion would indicate that no one is completely satisfied with the methods in common usage. A simple effective method with plaster, which allows the patient free use of both arms, is described here.

FIG. 1

The part of this procedure which is essentially different consists in keeping the scapula elevated by a sling under the axilla. This sling (Fig. 1) is composed of a fold of half-inch felt, a plaster reverse bandage, and a length of rope over which the plaster and then the felt are draped. The pull is directed upward and slightly medially, and the sling is fixed to an overhead support while the remainder of the device is applied (Fig. 2). While elevation is being maintained constantly, a circular plaster (Fig. 3) is added. A padded shoulder strap is next applied, the cast is allowed to set, and the suspending ropes are cut (Fig. 4).

The axillary crutch molds accurately and gives a comfortable support. Accurate approximation and a somewhat medial pull give an upward thrust, more against the glenoid process than the axillary vessels, and no circulatory or nervous involvement has been encountered. A good grade of fast-setting plaster is essential, and the rope should not be cut until sufficient time for hardening has elapsed. Six weeks is sufficient time for the healing of recent dislocations.

The first patient treated by this method was a young bricklayer with a non-industrial injury, who was reluctant to lose even a single day's work at his present wage scale. He was able to carry on this rather strenuous occupation with no loss of time. The cast was worn for six weeks, and required no adjustments during this period. The patient had an

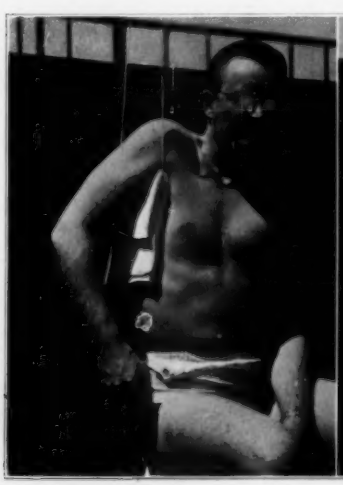

FIG. 2

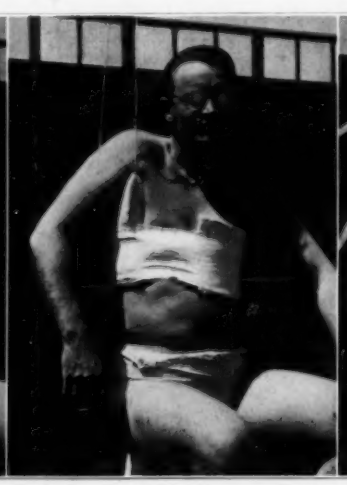

FIG. 3

FIG. 4

excellent anatomical and functional end result. In five more consecutive cases, the results were equally good. Only the patients with industrial injuries and one other, a commercial air-line pilot, lost any time from work.

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CONTROL OF POSITION OF LOWER EXTREMITY BY ELASTIC BANDAGE

BY DONALD T. IMRIE, M.D., VICKSBURG, MISSISSIPPI

The technique of applying hot packs in poliomyelitis has, through experience, been modified to meet certain individual variations. Especially when a lower extremity assumes an unnatural position because of poor muscle balance, it is desirable to control the position of that extremity more exactly than can be accomplished by packs alone. By using latex-weave elastic bandages, three or four inches in width, the packs can be held in place more readily than by pinning. At the same time, the wrapping can be so applied as to influence the position of the limb without rigidly immobilizing it.

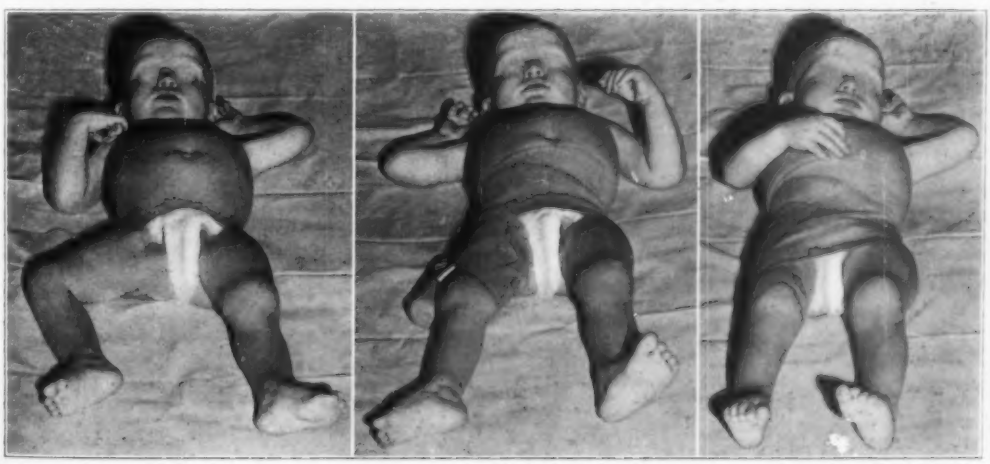


FIG. 1 FIG. 2 FIG. 3

Fig. 1: Position of flexion and external rotation assumed voluntarily by patient who recently has had poliomyelitis. The child has an imbalance of the right lower extremity, and contractures will develop unless the position of the extremity is controlled.
Fig. 2: Shows elastic bandage, which in this case is applied over a thigh pack.
Fig. 3: Tension has been distributed so as to maintain a neutral resting position.

One of the most frequent problems in this condition is the tendency for a lower extremity to fall into a position of external rotation and flexion (Fig. 1). In babies who have involvement of the internal rotators and short adductor muscles, contractures in this position are particularly apt to develop. A hip and thigh pack can be held in place simply by wrapping an elastic-bandage spica in such a way as to control the position of the limb and to maintain a neutral resting position (Figs. 2 and 3).

This simple measure is applicable in a great variety of orthopaedic problems.

THUMB ABDUCTION SPLINT

BY MAJOR J. W. LITTLER AND MAJOR W. J. TOBIN

Medical Corps, Army of the United States

From the Orthopaedic Section, Surgical Service, Cushing General Hospital, Framingham, Massachusetts

Adduction contracture of the thumb is a common finding in injuries of the hand and of the peripheral nerves. The correction of the deformity and the maintenance of proper position are important to the restoration of function. Counterpressure between the thumb and the second metacarpal is necessary, if narrowing of the interosseous space is to be corrected; and effective abduction traction of the thumb is possible only with this adequate counterpressure against the second metacarpal. Without this factor, attempted correction of thumb adduction results only in radial deviation of the entire hand at the wrist. In the authors' attempts to devise a satisfactory method of correcting this deformity, they have developed the splint herein described, and they have found it a most useful piece of apparatus.

FIG. 1

FIG. 2

Figure 1 shows the simplicity of the splint. Effective counterpressure is obtained by the well-padded bar, which rests against the second metacarpal. The transverse palmar bar is made to conform with the normal palmar arch.

Figure 2 shows the splint in place.

The splint is made of one continuous piece of brass welding rod or steel, and is attached to a removable forearm cuff of leather. The "arc" formed should be wide enough to permit a variation in direction of abduction with the carpometacarpal joint of the thumb as the center.

Dynamic splinting must be started early, if the adduction deformity is to be prevented. Surgical intervention will be necessary in long-standing cases in which mobilization by traction has failed.

SEMILUNAR-CARTILAGE KNIVES *

BY F. HAROLD DOWNING, M.D., FRESNO, CALIFORNIA

The two difficulties encountered in removing a meniscus (semilunar cartilage) seem to be the freeing of the posterior third of its peripheral attachment, and the cutting free of the remaining posterior attachment. The ordinary operative instruments are not satisfactory for either of these procedures. With the instruments which the author is presenting, these two technical difficulties may be overcome, and complete excision of the meniscus is possible through a single anterior incision.

The curved knife (Fig. 1, *a* and *b*) is designed to follow the peripheral margin of the meniscus to its posterior attachment, thus freeing the posterior third from its marginal attachments and synovial reflection. The anterior half of the meniscus must first be dissected free, either with the knife or with scissors (Fig. 2). This dissection is carried back to the posterior corner of the femoral condyle or, if on the medial side, to just past the anterior border of the tibial collateral ligament. With the knee flexed acutely, the curved knife is introduced, so that one of its blunt guides passes under the meniscus and the other over the meniscus and internal to the synovial fold (Fig. 3). The curved blade is then pushed against the peripheral margin of the meniscus; and the two guides, plus the curved narrow shaft, direct the blade in such a manner that the meniscus is freed from its peripheral attachment and there remains only its central posterior attachment to the tibia.

This knife does what the Lowe-Breck knife [1] cannot do, chiefly because of the width of its blade and shaft. The width of the Lowe-Breck knife prevents it from following closely the posterior curve around the femoral condyle, and forces the blade back into the popliteal space, thus failing to free the meniscus up to its central posterior attachment. The knife described here has only a small area of maximum width, a narrow, rounded, anatomically curved shaft, two well-rounded blunt guides, and a curved cutting edge, so that, as the blade is pushed forward, there is a tendency for the tissue to be forced toward the central portion of the cutting blade and not to either corner, as may occur with a flat blade. The blade is made of tooled steel which is tempered so that it may be sharpened to a razor edge with a small, pencil-shaped Arkansas stone.

The straight knife (Fig. 1,*c*) is designed to cut off the meniscus at its posterior central tibial attachment, either before or after it has been displaced into the intracondylar notch. The knife has a rounded cutting blade, so that it cuts with a pushing motion. The back of the blade is thickened to prevent breakage.

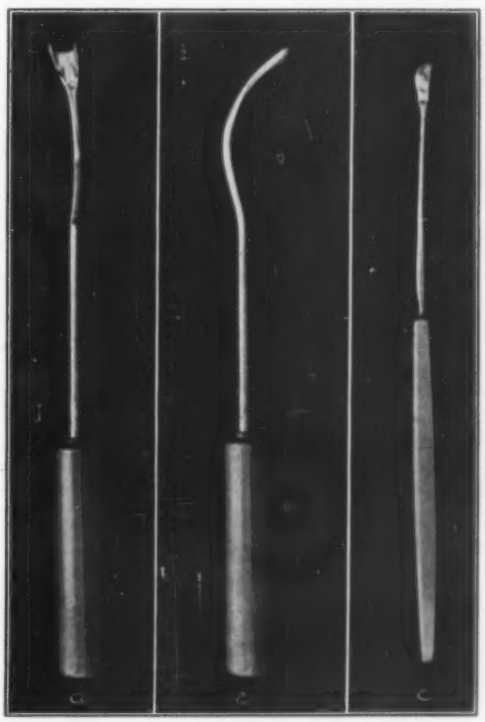


FIG. 1

Shows curved knife (*a* and *b*) and straight knife (*c*), devised for removal of the meniscus.

* Presented in a motion picture entitled "Arthrotomy of the Knee", and demonstrated in a Scientific Exhibit at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 25 to 29, 1947.

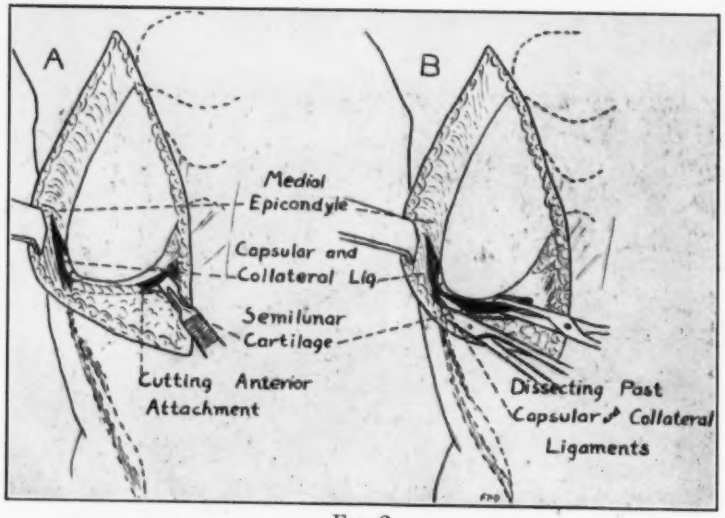
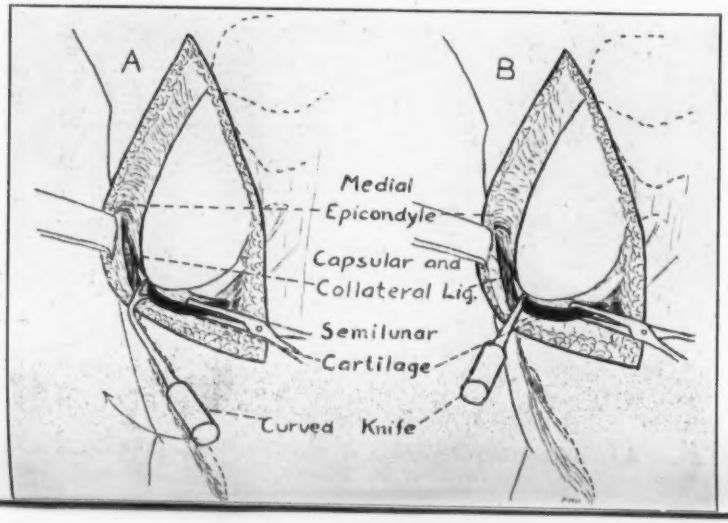


FIG. 2

Removal of the medial meniscus is begun by first cutting free the anterior attachment (*A*), and then dissecting around its periphery to just past the thickened portion of the medial collateral ligament (*B*).



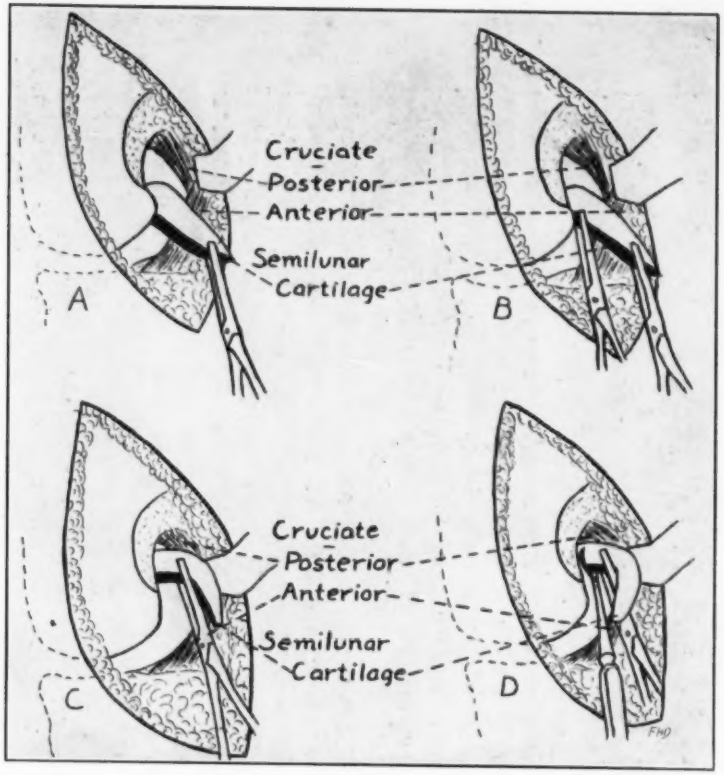


FIG. 4

Fig. 3: The curved knife, with its guide prongs central to the synovial and tibial reflections of the meniscus and its cutting edge past the anterior border of the medial collateral ligament, is pushed with a circular motion around the back of the joint, freeing the peripheral attachments of the posterior portion of the meniscus.

Fig. 4: In *A*, the meniscus is displaced into the intracondylar notch by the operator grasping the tip with an Ochsner clamp and exerting traction. In *B*, a second Ochsner clamp is placed as far posterior as possible on the displaced meniscus. By pushing posteriorly on the second Ochsner clamp, considerably more of the posterior portion of the meniscus becomes visible (*C*). A straight knife, with a blade that cuts with a pushing motion, is inserted (*D*) so that its back is toward the posterior cruciate ligament and its cutting edge is on the posterior attachment of the meniscus. With a few short cuts (pushes), the remaining posterior attachment is severed and the

The shaft is long and narrow. The usual technique is to dislocate the freed meniscus into the intracondylar notch; it is then grasped with an Ochsner clamp, as far back as possible, and pushed farther posteriorly. The blade of the knife is then introduced, so that the back of the blade is toward the posterior cruciate ligament and the sharp edge is against the central attachment of the meniscus. With a pushing motion, this attachment is severed. If any is missed, it can easily be located with the widened end of the blade, and the same motion can be repeated (Figs. 4 and 6). It is a mistake to pull forward on the cartilage. This places the cartilage at an acute angle to the blade, and may result in a long oblique cut rather than in a short transverse cut at the posterior tibial attachment.

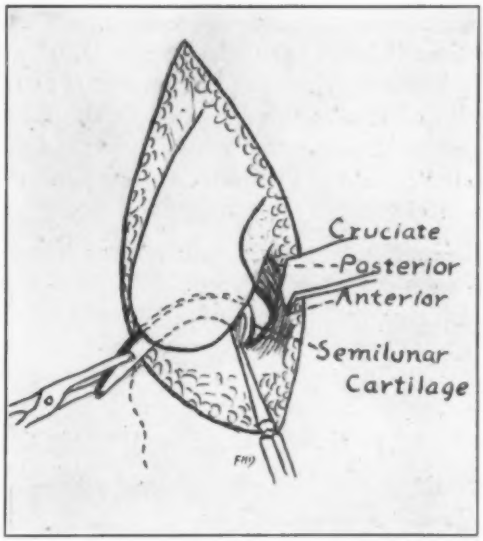


FIG. 5

Shows method of cutting free the remaining attachment of the meniscus without displacing it into the intracondylar notch.

In some instances the meniscus may be removed without its displacement into the intracondylar notch. This may be accomplished by pulling gently on the tip of the meniscus, after its periphery has been dissected free. The region of the posterior attachment may be seen to shake slightly, when viewed through the intracondylar notch. The blade of the

FIG. 6

FIG. 7

Fig. 6: Medial meniscus removed after displacement into the intracondylar notch.
Fig. 7: Medial meniscus removed without displacement into the intracondylar notch.

straight-shafted knife is placed against this remaining attachment and, with a pushing motion, it is cut free (Figs. 5 and 7).

These two knives were developed as the result of experience gained from 153 arthrotomies of the knee, performed in the Military Service, and came to be considered as essential instruments by nine different operators. Their use simplified the excision of the medial or lateral meniscus, and enabled the surgeon to close the joint at the end of the operation with a more reasonable degree of satisfaction.

1. Lowe, F. A., and Breck, L. W.: A New Knife for Use in Removing Semilunar Cartilages. J. Bone and Joint Surg., **20**: 220–221, Jan. 1938.

APPARATUS FOR CORRECTION OF FLEXION DEFORMITY OF THE KNEE

BY S. RALPH TERHUNE, M.D., BIRMINGHAM, ALABAMA

The apparatus depicted has been employed successfully for conservative correction of flexion deformity of the knee. This was devised on the principle described by Horwitz[1]. The turnbuckles have, however, been replaced by rubber bands. This method has proved

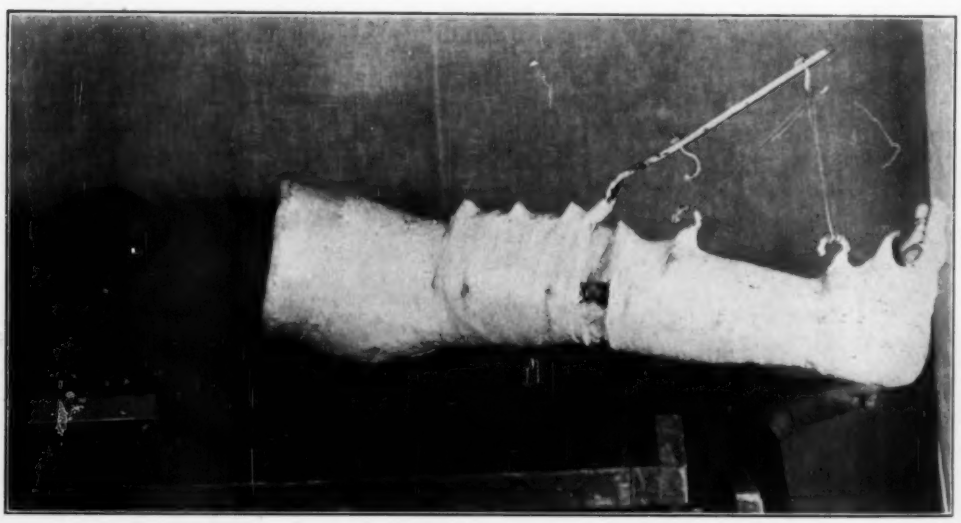


Fig. 1

to be superior to turnbuckle traction, in that the bands stay in place better and do not have to be changed.

The most important advantage is that the patient can constantly exercise the muscles and the knee joint, thus eliminating to a great extent the atrophy and stiffness which accompany fixed turnbuckle traction. This turnbuckle traction must be released for frequent periods, in order to prevent the development of pressure ulcers. Rubber-band traction can be maintained constantly, with the patient doing flexion exercises, and pressure ulcers are much less apt to occur.

1. Horwitz, M. T.: Conservative Method of Correcting Flexion Deformity of the Knee Complicated by Posterior Luxation of the Tibia. J. Bone and Joint Surg., **19**: 522–523, Apr. 1937.

APPARATUS FOR MAINTAINING ROTATION OF LOWER EXTREMITY WHILE IN TRACTION

BY HARRY R. WHEAT, M.D., SPRINGFIELD, MASSACHUSETTS

A certain number of fractures of the neck and trochanter of the femur are best treated by traction. The Russell method seems to be the most satisfactory. This or any other type of traction presents two difficulties: First, if skin traction is used, the adhesive requires constant watching for slipping and skin irritation. Second, there is also the difficulty of holding the limb in internal rotation until union has taken place,—thereby preventing a distressing outward-rotation deformity.

To overcome these difficulties the following routine has been used for the last two years with satisfactory results:

The patient is anaesthetized with a small amount of pentothal sodium. A Kirschner wire is inserted through the lower portion of the tibia, and the ends are left uncut. A well-padded plaster boot is applied with the dorsum of its foot and ankle cut away to allow active motion. After manipulation and reduction of the fracture, and after full internal rotation has been obtained, the apparatus is applied (Fig. 2-A) and traction is instituted. Complete reduction is necessary to prevent torsion strain of the knee.

The apparatus used consists of two tubes, twenty-six inches long, held by movable crosspieces at each end, which allow the width of the frame to be adjusted. The tubes are slotted to allow free excursion of the vertical assembly. The uprights are joined at their bases to a freely movable crosspiece to which is fixed a small foot plate. The uprights are furnished with adjustable fixtures with apertures which loosely hold the Kirschner wire. Up-and-down adjustment of these fixtures provides the desired degree of rotation.

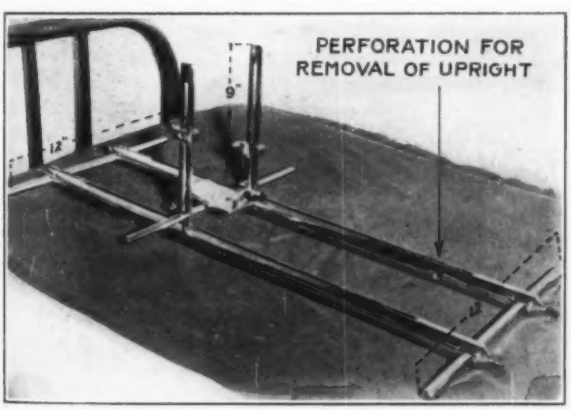


FIG. 1
Showing apparatus assembled.

FIG. 2-A

FIG. 2-B

Showing apparatus in use.

A SELF-TURNING SLING DEVICE

BY HERBERT E. HIPPS, M.D., WACO, TEXAS

The simple device described here makes it possible for a patient in a large, heavy body cast or a hip spica cast to turn himself, easily and without help, from his back to either side, and to maintain himself securely and comfortably in the desired position. It can be constructed and assembled at any hospital, by a nurse or orderly. The component parts are not expensive, and may be purchased at any hardware store.

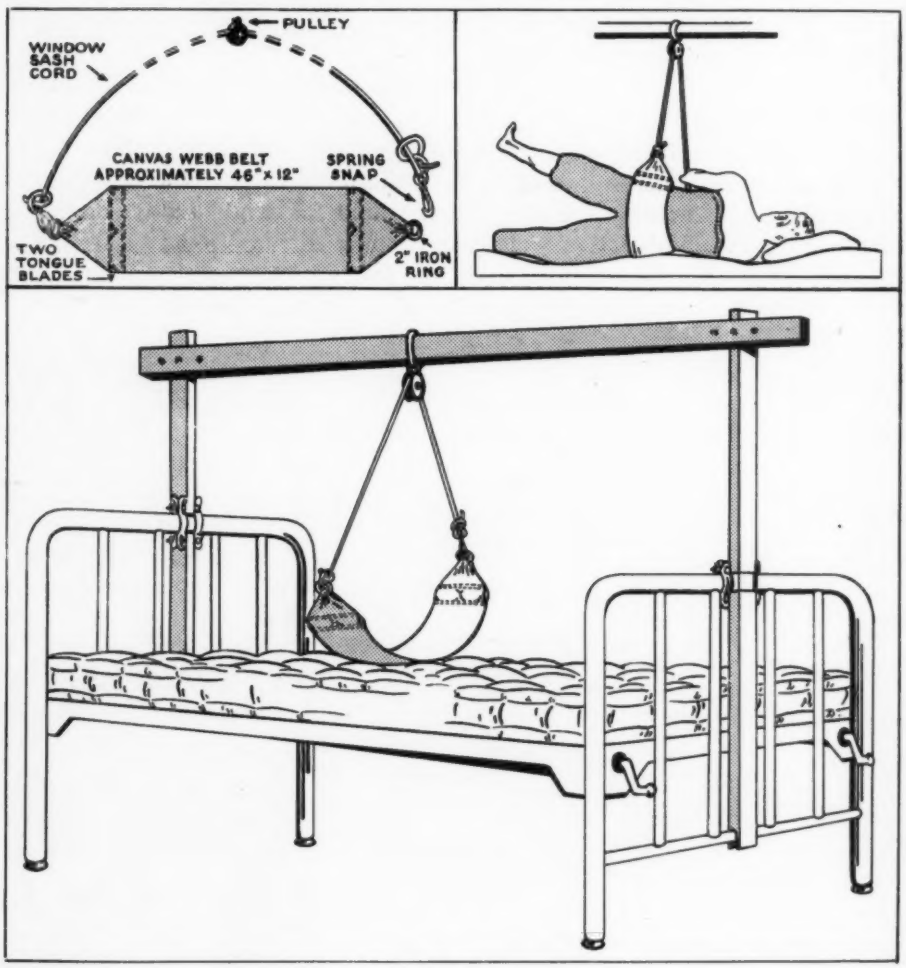


FIG. 1

The sling is of heavy duck or canvas material. Harness rings are sewed into each end. Transversely sewed-on linear pockets, into which tongue blades are thrust, prevent the sling from rolling up (Fig. 1).

The rope is window-sash cord, the pulley any ordinary one, and the spring snap is a device used on harness. An overhead bed frame, of the design which most hospitals usually have, is suitable for the pulley attachment.

The sling must support the patient at his approximate balancing center, usually about the pelvis. It must actually support or lift the patient, holding him about a quarter of an inch off the bed surface. The patient can easily turn himself in bed by pulling the rope on the side to which he wishes to turn.

RESULTS OF RECENT STUDIES AND EXPERIMENTS CONCERNING METALS USED IN THE INTERNAL FIXATION OF FRACTURES

BY C. S. VENABLE, M.D., AND WALTER G. STUCK, M.D., SAN ANTONIO, TEXAS

A Synopsis *, Prepared by Dr. Venable

At present, bone plates and screws are being placed upon the market, which may or may not be of suitable quality for use in bone-plating procedures. The reports on the metals used for such plates have been confusing. The purpose of this review is to clarify these reports.

In January 1941, the Committee on Fractures and Other Traumas of the American College of Surgeons, meeting in New Orleans, appointed a Subcommittee on Screws and Plates, composed of Dr. C. S. Venable, Chairman, Dr. Clay Ray Murray, and Dr. Huber Wagner. This Subcommittee was directed to undertake a comparative study of various metals with respect not only to their inertness in the tissues and resistance to corrosion, but also to their physical and mechanical qualifications to meet the requirements of bone surgery.

After a year the Subcommittee presented a report of progress, together with plans for further study, to the Committee on Fractures and Other Traumas of the American College of Surgeons [1] at its Washington meeting. Since no funds for this proposed work were made available by the Regents of the College, the matter was referred to the Committee on Medical Research of the Office of Scientific Research and Development; and a grant for further research was made in 1942. With this grant from the Committee on Medical Research, the whole problem was submitted to Columbia University, where Professor Colin Fink, head of the Graduate Engineering Department, was assigned to study and report the electrochemical and physical findings and make recommendations regarding the adaptability and applicability to bone surgery of the materials submitted for study, in accordance with specifications based on clinical data supplied by the Subcommittee. Dr. Clay Ray Murray was assigned to undertake the study of tissue reaction to these metals in the animal experiments. These were to be conducted at Columbia Medical Center, since Dr. Murray had all the needed facilities at hand for such experiments *in vivo* and was thoroughly familiar with the subject and the ends sought.

The materials selected for this study, which in the opinion of the Subcommittee seemed most nearly to meet the required qualifications, were 18–8 stainless steel plus molybdenum (SMo), 19–9 stainless steel passivated in nitric acid, Vitallium, and tantalum.

In August 1944, the Subcommittee met in New York to review the data at hand and to prepare its report. At that time the experiments carried on by Professor Fink had not been completed, and the final report was not available. Therefore, the Subcommittee reported on the basis of the information then available:

"1. Vitallium, '19–9 stainless steel', and '18–8 SMo stainless steel' are inert in the tissues in descending order of excellence.

"2. Combinations of these metals should not be used in any single operation.

"3. The ability to withstand functional strain during the healing period is greater in the 'stainless steels' than in the Vitallium plates and screws which were tested. However, more recent improvements in production of Vitallium plates and screws entailing the use of x-ray testing for casting defects have produced Vitallium plates and screws which are on a par with the two 'stainless steels' in regard to the resistance to functional strain.

"4. Plates of either of the 'stainless steels' considered must be machined rather than stamped and the screws must be precision machined.

"5. All screws should be of the standard machine type with sharply cut threads and should have a short self-tapping end with a right-angle Mills cutting edge.

"6. Screws without a tap and tapering screws are inadvisable in living bone unless a tap for the screw is made in the bone before the screw is inserted.

"7. The heads on all screws should be made as flat as possible since countersinking of these screws in the plates is inadvisable. The countersunk hole weakens the plate.

"8. 'Stainless steel' plates and screws should be surface marred as little as possible during application. If badly scratched or abraded they are subject to increased corrosion in the tissues. Neither plates nor screws should ever be used a second time. It is obvious that non-slipping screw drivers are needed for the insertion of screws and that the plates should be protected from scratching by the instruments with which they are handled.

"9. Following bending, deep surface scratching or severe strain 'stainless steel' plates and screws show increased corrosion in the tissues and increased liability to breakage from fatigue strain.

"10. From studies of weight loss after exposure to the tissues and to blood serum under varying con-

* Paper was presented in full at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

ditions both before and after strain, it is apparent that there may be no fear of deleterious poisonous action from any of the three metals cited as satisfactory.

"11. No screw holds well in cancellous bone. Wider threads to increase the holding power merely intensify the concentration strain on the screw with an increased absorption rate of calcium about the screw. Screws attempting to fix cancellous bone should have a firm grip on the distal cortex or a bolt should be used in place of them.

"12. All screws in long bones should penetrate both cortices where possible and should be inserted at right angles to the surface of the plate holes or to the surface of the bone if no plate is used. If placed at an angle in bone without a plate, the screw head should be countersunk to prevent shearing strains on the neck of the screw. This latter procedure should always be followed in the use of transfixion screws which are at an angle to the surface of the bone.

"13. Plates should be of adequate length and with a sufficient number of screw holes to distribute the strain so that no undue strain is borne by any individual element, plate or screw.

"14. The drill holes should be made by a drill slightly smaller than the shank of the screw without its thread and the drill should be carefully protected against wobbling or reaming as the hole is drilled. Excessively high speed drills are to be avoided."

By macroscopic examination, the tissues adjacent to the steel screws and plates showed evidence of discoloration. Biochemical examinations of the adjacent tissues to determine which metals had been dissolved were not made, although this test was recommended in the original agenda of 1941 for this review and study.

On the basis of the data submitted, it was agreed by the Subcommittee that 18–8 SMo steel, designated as "Specifications 316 and 317" by the American Steel and Iron Institute, was suitable for internal fixation of fractures for the period of healing. This restriction did not apply to Vitallium, which could be left in the body indefinitely.

The report of the Committee on Medical Research was completed in June 1944, and forwarded to the National Research Council. The Subcommittee only became aware of this in May 1946. Thus when the Subcommittee met again in New York, in December 1944, it did not have access to the experimental findings of the Committee on Medical Research. The final report of the Subcommittee was then prepared and submitted to the Fracture Committee of the American College of Surgeons at Atlantic City, in January 1945. This explains the inconsistencies in the two reports. In the Subcommittee's report, it was stated that there was "marked variability of the individually cast Vitallium plates". The consequent threat of breakage, while changed qualitatively (by x-ray review before use) "remained quantitatively unchanged in contradistinction to the stainless steels". In addition, in these tests, "there was demonstrated a marked variability in the individually cast Vitallium plates. This amounted to a thirty percent variation" as related to the strength of such plates.

Now it is learned that Professor Fink's report to the Committee on Medical Research actually stated that in corrosion tests of nickel-plated screws, in which electrolytic etching was performed to determine the thickness and sharpness of the thread: "Readings of thickness often varied as much as 30% or more". This obviously has nothing to do with the suitability of Vitallium plates for internal fixation.

Elsewhere in the Subcommittee's report it is asserted: "This variability in Vitallium was true even in those plates which had been x-rayed and found by x-ray to be without casting deficiencies, carbon spots or air bubbles". "The ability to withstand functional strain during the healing period is greater in the 'stainless steels' than in the Vitallium plates and screws which were tested. However, more recent improvements in production of Vitallium plates and screws entailing the use of x-ray testing for casting defects have produced Vitallium plates and screws which are on a par with the two 'stainless steels' in regard to the resistance to functional strain."

In the report of the Committee on Medical Research, however, an opposite view is taken. "Table No. VII generally indicates slightly larger corrosion rates for strained plates than for unstrained plates, except for Vitallium. . . . In straining, the plates were bent to a 90 degree angle and straightened. This treatment caused the Vitallium to display large crystals at the site of the bend and also caused cracks to form!" The steels, after such extreme bending, develop anodic and cathodic points which become specific foci for corrosion. This is a much worse complication than the formation of crystals or cracks.

The Subcommittee concluded its report as follows:

"Tantalum is not suitable for use as plates or screws for internal fixation of fractures.

"Of the two stainless steels, the overall consideration of this Committee is that the equivalent of 18–8 SMo steel is the more desirable of the two stainless steels, as designated by the American Steel and Iron Institute, Specifications 316 and 317.

"It would, therefore, be the opinion of this Committee that Vitallium under the conditions in this discussion and the stainless steel identified by the American Institute and the above stainless steel are the two metals which we recommend as acceptable."

"At this time particularly this Committee feels that such standards should be created upon sound principle to be submitted to the Bureau of Standards and subsequently submitted to the Department of

Commerce for its approval, and then to the Congress to be placed in the Food and Drug Act in order to assure for the future that only materials which meet these requirements may be offered for sale".

So far, the Bureau of Standards has devoted most of its attention to torsion strength, ductility, and hardness of metal plates and screws, rather than to freedom from electrochemical effects in the body. The result has been that various types of stainless steel have been endorsed which are definitely deleterious in the body. Also, instrument makers are still selling "stainless steels" with varying properties which are not universally suitable in the body.

It is unfortunate that these contradictions have appeared in the various official reports on this subject, because the individual surgeon is thus left more confused than ever. The original plan of the Fracture Committee of the American College of Surgeons was to establish a specific standard which could be depended upon by everyone. This objective failed because divergent opinions were voiced by different committees, and no single accepted view was expressed by all. However, the Fracture Committee now has access to all the reports on the effects of metals on bone, and should be in a position to proceed to some type of standardization in conjunction with the Bureau of Standards.

REFERENCES

1. Committee on Fractures and Other Traumas, American College of Surgeons: Report of Subcommittee on Plates and Screws. Proc. Twenty-third Annual Meeting, Atlantic City, N. J., Jan. 26–27, 1945.
2. Committee on Medical Research, Office of Scientific Research and Development (Report No. 17, by Colin G. Fink): Use of Metal in Internal Fixation of Human Bone Fractures, Dec. 1944.
3. Venable, C. S., and Stuck, W. G.: The Internal Fixation of Fractures. Springfield, Illinois, Charles C. Thomas, 1947.

DISCUSSION

Dr. J. Albert Key, St. Louis, Missouri: Dr. Venable and I have quarreled for years in a friendly manner over the relative merits of Vitallium and stainless steel. Vitallium is the better material to use if you want to avoid irritation in the tissues or electrolytic reaction. It has the disadvantage that it cannot be machined or drawn into wire; it must be cast. The surgeon who uses it should have the ability to judge the mechanical factors that it will be called upon to withstand. We are going to have plates and screws of stainless steel or of Vitallium torn out or broken. I know a good deal about bone surgery and internal fixation, but I have had plates fail, not because of anything inherently wrong with the material used, but because they were used unwisely. You have to add external fixation in cases where internal fixation is not enough. I have used dual plates in recent years, omitting external fixation. You cannot do it with ordinary plates, because they will break or bend or tear out, whether they are Vitallium or stainless steel. My opinion is that there is a place for both metals.

One must not put two types of stainless steel in the same wound. I have reported cases in which there was electrolysis with very marked absorption around the screws; when I removed those screws they were black, yet they had been sold as stainless steel. I do not know which of the stainless steels is the better. With Vitallium, we always know where we stand.

Dr. Leonard Peterson, Washington, D. C.: Materials for internal fixation should be of the highest quality so that, with proper surgical technique, no failures will occur as a result of electrolysis, faulty design, or inadequate strength. The material should be physiologically inert in the body; and in this respect we have two metals which are suitable, Vitallium and the stainless steel known as 18–8 SMo. The designation of 18–8 SMo is applied to a range of high-alloy stainless steels, containing from 15 to 19 per cent. chromium, 8 to 14 per cent. nickel, and 2 to 4 per cent. molybdenum. This explains the designation, SMo, which means steel fortified with molybdenum. If we speak of stainless steels as a group, we will encounter many outside this formula which are not inert and which, if mixed with each other, can set up serious electrolysis. However, 18–8 SMo meeting proper specifications is physiologically inert for all practical purposes, and compares favorably with Vitallium in this respect. In addition to the specified composition, the hardness of the final product should be specified, since variable hardness may cause electrolytic reaction. A hardness of Rockwell 30 to 35 on the C scale has been adopted as standard.

Unfortunately, the physical characteristics of metal have not received proper emphasis in the search for inert material. In an effort to correct existing deficiencies in composition, design, and manufacturing, new tentative Army specifications were prepared in cooperation with the National Bureau of Standards. The metal adopted was 18–8 SMo, hardness 30 to 35 Rockwell C. Plates were limited to six sizes, which include practically all the lengths previously made in eleven sizes. For increased strength and rigidity, plates were made with a straight mid-section, similar to the design used in Canada. They combine the desirable features of the Sherman catenoid plate,—namely, uniform bending, and of the Venable straight plate,—namely, increased strength in the mid-section, where it is needed. Nearly everyone concerned agrees that this new type could replace both of the other types of plates without any advantage being lost. The plate should be bent by suitable bending irons to fit the bone before application, in order to avoid a spring tension effect on the screws. Precautions against bending as required are, in my opinion, without clinical importance.

Screws have been adopted with a cruciate head, which possesses advantages similar to the Phillips head. The Phillips head cannot be made economically in 18–8 SMo because of its hardness, and the simple slotted head is obviously inadequate. Two improved flutes are provided, and a pilot or guide point is an optional feature. The drill point of optimum diameter, based on numerous tests at the Bureau of Standards, is made of distinctive shape and length, of the same metal as the plates and screws, and is unbreakable, in contrast to the frequent breakage of drills previously encountered.

While the inert quality of Vitallium is recognized, its strength and fatigue resistance are inferior to 18–8 SMo and, furthermore, no method of manufacture, inspection, or testing has been verified which will absolutely exclude defective Vitallium plates. In the report of the Committee on Fractures and Other Traumas of the American College of Surgeons, Atlantic City, New Jersey, January 1945, Dr. Venable's Subcommittee on Plates and Screws reported: "Vitallium was found in many instances to be the complete equal of the SMo steel as regards these tests, but throughout the investigation there was demonstrated a marked variability in the individually cast Vitallium plates. . . . The stainless steel showed a remarkable uniformity on the other hand. . . ." This report is based on the research conducted by Professor Colin Fink at Columbia University, under the auspices of the Office of Scientific Research and Development. The final report by Professor Fink concluded that Vitallium and 18–8 SMo were equal in corrosion resistance. Plates were tested by bending and straightening. This caused the Vitallium to display large crystals at the site of the bend and also caused cracks to form. While Dr. Venable has previously claimed that Vitallium is the only metal which appears to be uniformly inert, the results shown in the Fink report indicate differently, since both Vitallium and 18–8 SMo were found suitable from the physiological standpoint. In respect to the physical properties investigated by the National Bureau of Standards, I quote the following from a report by Dr. L. B. Tuckerman, December 17, 1946: "Our examination and tests of Vitallium bone plates have confirmed the statements made in the committee report about the variability of the mechanical properties of these plates. Several Vitallium plates removed from soldiers' legs in Army hospitals because of brittle fractures showed only local brittleness. . . . We were unable to correlate these areas of local brittleness with any chemical segregation or differences in microstructure or with local variations in indentation hardness."

"The seriousness of the results of a single broken plate in a man's leg makes us reluctant to write any specification for bone plates which does not ensure that *no single* brittle plate shall be accepted. . . . The presence of local brittleness is not revealed by x-ray inspection.

"So far as we can see the absolute exclusion of the possibility of occasionally accepting Vitallium plates having local brittleness could only be obtained by reliable non-destructive tests which could be applied to each individual plate. We know of no such tests. . . .

"We have also made many tests of 18–8 SMo plates. Our tests have confirmed the statements made in the committee report about the uniformity of this material. Plates cold worked to the same Rockwell C hardness gave uniform strength. Plates of higher Rockwell C hardness gave, as was to be expected, higher strength. In no case did we have a brittle failure. The plates could be bent and straightened many times without brittle fracture . . ."

In conclusion Dr. Tuckerman states: "At present as explained above we can only see our way clear to write specifications for plates made of 18–8 SMo".

Dr. Clay Ray Murray, New York, N. Y.: I would like to augment some of the things Dr. Peterson had to say. I spent almost three years on the investigation of this problem in cooperation with Professor Colin Fink of the Engineering Department at Columbia University. These studies, made under the auspices of the Office of Scientific Research and Development, were in large part the basis for the report rendered to the Committee on Fractures and Other Traumas of the American College of Surgeons. The factual findings were that 18–8 SMo stainless steel, 19–9 stainless steel, and Vitallium were all acceptable for use as plates and screws. It was agreed that, of the three, Vitallium was the most inert in living tissue. It was further agreed that none of the three produced sufficient reaction to cause physiological disturbance, interfering with the healing of bone or soft parts. It was agreed that mixing two different types of metal might cause physiological disturbance, and that this practice was distinctly undesirable. It was factually demonstrated that, in response to mechanical strain tests, the stainless steels were remarkably constant, but that there was a considerable variation among the individual Vitallium castings in their response to the same tests. These being factual findings, there could be no disagreement among the Committee members in regard to them.

Dr. Walter G. Stuck (closing): I appreciate the remarks of the discussors. The subject is too vast to cover in a few minutes. I therefore feel like our Open Forum speakers who, when asked questions, reply: "You will find the subject well covered in my latest book".

JOSEPH B. L'EPISCOPO

1890–1947

On September 5, 1947, after a protracted illness, Joseph B. L'Episcopo died in New York. The medical profession lost an esteemed practitioner of medicine and a well-known orthopaedic surgeon.

For about seven years prior to his death, he was Professor of Orthopaedic Surgery at the Long Island College Hospital, where he had served his internship.

During World War I, Dr. L'Episcopo served as First Lieutenant in the Medical Corps of the United States Army. After returning to private practice, he devoted himself to the development of the Orthopaedic Department of the Long Island College Hospital. He also became the Director of Orthopaedic Surgery at Kings County Hospital, Carson Peck Memorial Hospital, Bushwick Hospital, House of St. Giles the Cripple, and many other institutions throughout Brooklyn and Long Island.

As a Fellow of the American College of Surgeons, he was deeply interested in its activities. He was a member of The American Orthopaedic Association and a charter member of The American Academy of Orthopaedic Surgeons, and he was extremely interested in their activities.

Dr. L'Episcopo was born in Italy, and came to this country at the age of eight. Among the outstanding features of his professional career in the community in which he lived was his intense loyalty to organized medicine in all its branches. He was a frequent contributor to the literature in his specialty, a keen student of anatomy throughout his life, an able and competent surgeon, and a teacher. Perhaps his most characteristic traits were his gentleness of manner and firmness of purpose. It was his desire at all times to lend a helping hand to his students, interns, and residents, by whom he was revered. Up to three days before his death, he was still making plans for the betterment of the Long Island College of Medicine and for the improvement of services of the various members of his Staff. He possessed a gentleness tempered with firmness, an intelligence impregnated with years of clinical experience,—a teacher, a scholar, and above all a gentleman.

His passing is a distinct loss, and an untimely one, to the profession and the specialty which he served so nobly. Those who had the privilege of knowing him intimately will never forget his influence on their lives.

PIERO PALAGI

1879–1947

Professor Piero Palagi, one of the best known and most colorful of the orthopaedic surgeons in Italy, died in Florence on March 18, 1947. He was born on December 29, 1879, in Bibbiena, Tuscany. He was graduated from medical school in Florence in 1902, and did postgraduate work at the hospitals for internal medicine and general surgery in Florence until 1905. In 1906 he became associated with the great orthopaedic hospital, *Istituto dei Rachitici*, in Milan, where he worked for nearly three years under the guidance of the noted Italian orthopaedic surgeon, Galeazzi. Subsequently Palagi did postgraduate work at other orthopaedic institutions abroad, mostly in Germany.

During the first World War he performed distinguished service as a military surgeon, and was head of the first specialized service for the treatment of bone and joint casualties. After the war, Palagi was nominated chief of the section of orthopaedic and traumatic surgery in the Department of Surgery at the University of Florence; he directed that service from November 1918 to May 1923, when he became chief of the *Istituto Ortopedico Toscano*, the orthopaedic hospital of the University. From a relatively modest orthopaedic hospital (thirty beds in 1923, when Palagi took over its direction), the *Istituto Ortopedico Toscano* developed gradually during the following twenty-four years into one of the finest orthopaedic institutions in Italy.

Since 1925, Palagi had occupied the Chair of Orthopaedics and Traumatic Surgery at the University of Florence. With almost a quarter of a century of teaching and innumerable courses of lectures to general practitioners, country physicians, health officers, and nurses, Palagi contributed greatly to the diffusion of orthopaedic knowledge throughout the profession and to the realization of the importance of orthopaedic surgery which, until a few years ago, had been considered but a stepchild of surgery. Together with Putti, his lifelong and intimate friend, Palagi undertook a true crusade for the early recognition and treatment of congenital dislocation of the hip, a disease frequent in Italy, particularly in Tuscany.

In more than fifty scientific papers, monographs, and reports at Italian and international meetings, he made several important contributions.

Aside from his qualities as surgeon and teacher, Palagi was outstanding for his personality, which left a deep and lasting impression on all who have had the privilege of being associated with him. He was a gentleman in the noblest sense of the word, straightforward and courageous at a time when few people in Italy had the fortitude to stand for their convictions. He gave all of himself to his profession. He is deeply missed by his many friends and associates.

News Notes

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Fifteenth Annual Convention of The American Academy of Orthopaedic Surgeons will be held at the Palmer House, Chicago, January 24, 25, 26, 27, 28, and 29, 1948, under the presidency of Dr. Rex L. Diveley.

Registration will begin at nine o'clock Saturday morning, January 24. Scientific and Technical Exhibits will be ready for inspection at that time. During the afternoon the Audio-Visual Education Program will be presented under the chairmanship of Dr. Charles N. Pease. At seven o'clock Saturday evening the Instructional Course Dinner will be given, at which time an "Information Please" program will be presented. This will offer to members present an opportunity to "stump the panel of experts".

The Audio-Visual Education Program will continue on Sunday morning from nine o'clock until noon. The Instructional Courses will begin at two o'clock Sunday afternoon and continue until noon on Monday. The following Courses will be offered.

Course I

Abnormal Anatomy of the Lumbosacral Region with Reference to Low-Back Pain	Dr. Theodore A. Willis
Roentgenography in Low-Back Pain	Dr. Albert Ferguson
The Medical Aspects of Low-Back Pain	Dr. J. G. Kuhns
The Conservative Treatment of Low-Back Pain	Dr. Paul C. Williams
The Operative Management of Low-Back Pain	Dr. Joseph S. Barr
Lumbosacral Fusion	Dr. David M. Bosworth
Surgical Treatment of Low-Back Pain	Mr. H. Osmond Clarke

Course II

Postoperative Care	Dr. Walter G. Maddock

Course III

Medical Aspects of Arthritis	Dr. Richard H. Freyberg
Orthopaedic Treatment of Arthritis	Dr. Carl E. Badgley

Course IV

Anatomy of the Hand	Dr. J. E. Markee

Course V

Vascular Phenomena in Orthopaedics	Dr. Donald S. Miller Dr. David I. Abramson

Course VI

Plastic Surgical Problems Related to Adult Orthopaedics	Dr. Paul W. Greeley
Principles and Practice of Plastic Surgery as Related to the Care of Crippled Children	Dr. H. R. McCarroll

Course VII

The Treatment of Acute Hematogenous Osteomyelitis	Dr. Robert C. Robertson

Course VIII

Vascular Tumors of Bone	Dr. Henry W. Meyerding Dr. Dallas B. Phemister Dr. David G. Pugh Dr. Bradley L. Coley Dr. Norman L. Higinbotham

Course IX

Painful Hips in Children	Dr. Leo S. Lucas

COURSE X

Tuberculosis of the Spine in Children ..... Dr. Edwin F. Cave
Tuberculosis of the Lower Extremity in Children ..... Dr. Fremont A. Chandler
Tuberculosis of the Upper Extremity in Children ..... Dr. George J. Garceau

COURSE XI

Seminar on Scoliosis ..... Dr. Joseph C. Risser

COURSE XII

Psychosomatic Problems in Orthopaedic Surgery ..... Dr. J. Vernon Luck

COURSE XIII

Hip Surgery ..... Dr. Paul H. Colonna

COURSE XIV

Endocrines in Bone Metabolism ..... Dr. Irvin Stein

COURSE XV

Seminar on Amputations of the Lower Extremity ..... Dr. Rufus H. Alldredge

COURSE XVI

Practical Foot Problems ..... Dr. Walter R. Fischer

COURSES XVII & XXXIV

Disability Evaluation ..... Dr. Earl D. McBride

COURSE XVIII

Seminar on Plastic Surgery ..... Dr. Paul W. Greeley

COURSE XIX

Anatomy of the Shoulder ..... Dr. Claude N. Lambert
Anatomy of the Hip ..... Dr. John J. Fahey

COURSE XX

Scoliosis ..... Dr. Harold E. Crowe
Dr. Wm. H. Von Lackum
Dr. John R. Cobb
Dr. Joseph C. Risser

COURSE XXI

Muscle Physiology ..... Dr. Charles O. Bechtol

COURSE XXII

The Surgical Treatment of Poliomyelitis ..... Dr. C. E. Irwin

COURSE XXIII

Chemistry of Bone Lesions ..... Dr. Irvin Stein

COURSE XXIV

The Cerebral Palsies ..... Dr. W. M. Phelps

COURSE XXV

Arthroplasty of the Hip ..... Dr. M. N. Smith-Petersen

COURSE XXVI

Treatment of Congenital Club-Foot ..... Dr. J. Hiram Kite

COURSE XXVII

Conservative Management of Lesions of the Lumbosacral Spine ..... Dr. Paul C. Williams

COURSE XXVIII

Surgical Approaches: Upper Extremities . . . . . Dr. H. Herman Young
Surgical Approaches: Lower Extremities . . . . . Dr. Wm. Schnute

COURSE XXIX

Internal Fixation of Fractures . . . . . Dr. Walter G. Stuck

COURSE XXX

Seminar on Arthritis . . . . . Dr. Richard H. Freyberg

COURSE XXXI

Hand Surgery . . . . . Dr. Walter C. Graham

COURSE XXXII

Roentgen Diagnosis of Bone Tumors . . . . . Dr. Albert B. Ferguson

COURSE XXXIII

Roentgen Diagnosis of Bone Tumors . . . . . Dr. Albert B. Ferguson

COURSE XXXV

Hemipelvectomy . . . . . Dr. Don King

On Monday afternoon, Tuesday, Wednesday, and Thursday morning, the Scientific Program will be given.

There will be Executive Sessions at noon on Tuesday and at noon on Thursday, for members only.

The following program has been selected by the Program Committee under the chairmanship of Dr. T. Campbell Thompson.

MONDAY, JANUARY 26

Afternoon Session

Occurrence and Management of Reflex Sympathetic Dystrophy-Causalgia of the Extremities.
James W. Toumey, M.D.

The Use of Iliac Bone Grafts in Orthopaedic Surgery.
I. S. McReynolds, M.D.

Fractures of the Carpal Scaphoid.
H. Osmond Clarke, F.R.C.S. (London, England)

Delayed Bone Graft in the Treatment of Congenital Pseudarthrosis.
John R. Moore, M.D.

Short First Metatarsal—Its Incidence and Clinical Significance.
T. Beath, M.D.
R. I. Harris, M.B.

TUESDAY, JANUARY 27

Morning Session

Legg-Perthes Disease—A Method of Conservative Treatment.
Maurice M. Pike, M.D.

The Relationship between Congenital Subluxation and Congenital Dislocation of the Hip.
Vernon L. Hart, M.D.

Treatment of the "True" Congenital Luxation of the Hip. Results of the Open Reduction.
Professor Jacques Leveuf (Paris, France)

Symposium on Orthopaedic Rehabilitation—Frank Stinchfield, M.D., Chairman

Aspects of Physical Reconditioning.
Marcus J. Stewart, M.D.

Vocational Rehabilitation.
Michael J. Shortley, M.D.

Rehabilitation of the Severely Handicapped.
Henry H. Kessler, M.D.

Afternoon Session

Dupuytren's Contracture: A Report of Fourteen Cases of Combined Palmar and Plantar Lesions.
J. Vernon Luck, M.D.

The Problem of the Lumbar Intervertebral Disc—Some Pathological and Clinical Aspects.
Professor Sten Friberg (Stockholm, Sweden)

Criteria for Spine Fusion Following Removal of Protruded Nucleus Pulposus.
Guy A. Caldwell, M.D.
William B. Sheppard, M.D.
The Problem of the Primary Curve in Idiopathic Scoliosis.
John R. Cobb, M.D.
Changing Concepts in Scoliosis.
W. H. Von Lackum, M.D.

WEDNESDAY, JANUARY 28

Morning Session

Symposium on Treatment of Fractures of the Long Bones—Mather Cleveland, M.D., Chairman
The Use of Skeletal Traction in the Treatment of Fractures of the Femur.
Edward M. Winant, M.D.
Open Reduction and Internal Fixation of Long-Bone Fractures.
Harrison L. McLaughlin, M.D.
External Skeletal Fixation in the Treatment of Tibial Fractures.
John R. Naden, M.D.
Surgical Treatment of Non-Union of Long Bones.
Dr. Robert Merle D'Aubigne (Paris, France)
Presidential Address.
Rex L. Diveley, M.D.

Afternoon Session

The Cervical Syndrome as a Causative Factor in Certain Shoulder Disabilities.
Ruth Jackson, M.D.
Margaret Watkins, M.D.
Aseptic Necrosis of the Femoral Head.
Joseph M. Regan, M.D.
Ralph K. Ghormley, M.D.
Early Effects of Partial Denervation of the Hip for Relief of Pain in Chronic Arthritis of the Hip.
Benjamin E. Obletz, M.D.
Hamstring-Tendon Transplantation for the Relief of Quadriceps Paralysis in Residual Poliomyelitis.
J. R. Schwartzmann, M.D.
C. H. Crego, Jr., M.D.
Traumatic Proliferations of Fibrocartilage with Ossification in the Genesis of Spondylitis Deformans and Traumatic Myositis Ossificans.
Edwin F. Hirsch, M.D.

THURSDAY, JANUARY 29

Morning Session

The Status of Lumbosacral Fusion. An Operation of Transfacet Mortised Bone Block.
Earl D. McBride, M.D.
Arthrodesis of the Spine. An Ankylosing Method Permitting Early Ambulation.
Roger Anderson, M.D.
Ivan Loughlen, M.D.
Pen-Chien T'Ung, M.D.
The Flexion Block Fusion with Screw Fixation of Facets.
O. Anderson Engh, M.D.
Acute Anterior Dislocation of the Shoulder.
Toufick Nicola, M.D.
Posterior Dislocation of the Shoulder.
John C. Wilson, M.D.

The Annual Dinner will be held on Wednesday evening, and on Tuesday evening a stag smoker, which will give the members an opportunity to meet our distinguished foreign guests.

The American Society for Surgery of the Hand will meet in Chicago on January 23 and 24, in conjunction with The American Academy of Orthopaedic Surgeons. The preliminary program of the meeting was published in the October issue of *The Journal*.

A six-week course in **General Orthopaedic Surgery and Traumatology,** beginning on February 2, will be conducted by Dr. Arthur Steindler and associates at the College of Medical Evangelists, Los Angeles.

The National Society for Crippled Children and Adults, Inc. will hold its usual sale of Easter seals. These seals will be sent in letters from the State Societies, early in March. The gross return from the sale of Easter seals in 1947 was one million dollars more than in the previous year. This money is used to provide needed services to crippled children in forty-three states, and in Hawaii and Alaska.

An intensive **Postgraduate Course in Orthopaedic Surgery** will be given at the Medical Center and the San Francisco County Hospital February 9 through 13. The general chairman of the course is Dr. LeRoy C. Abbott, Professor of Orthopaedic Surgery, University of California Medical School. Requests for application should be addressed to Stacy R. Mettier, M.D., Head of Postgraduate Instruction, Medical Extension, University of California Medical Center, San Francisco 22, California.

Dr. Dallas B. Phemister of the Department of Surgery, University of Chicago, was awarded the Danis Prize on September 15, 1947, at the meeting of the International Surgical Society, held in London, because of his work on "Treatment of Ununited Fractures by Onlay Grafts without Screw or Tie Fixation". The fund for this prize was established by the pupils and friends of Robert Danis, for many years Professor of Surgery at the University of Brussels. The prize is awarded at the meeting of the International Surgical Society, which usually takes place every three years, and is given for the most important work on the operative treatment of fractures.

The second annual meeting of the **New Jersey Orthopaedic Society** was held at the Hospital and Home for Crippled Children, Newark, on October 11, 1947. The scientific program, arranged by Dr. Toufick Nicola and his committee, included the following papers:

Shelf Operation for Congenital Dislocation of the Hip—Harry Merliss, M.D. (by invitation)
Scoliosis: Rapid Method of Correction of Deformity Preliminary to Spine Fusion—Vincent Scudese, M.D. (by invitation)
Basile Operation for Flat Feet—H. Kunz, M.D. (by invitation)
Amputations in Europe—Henry H. Kessler, M.D.
Saucerization and Skin-Grafting for Chronic Osteomyelitis—J. J. Flanagan, M.D.
Bone Tumors in Children—E. Seifert, M.D. (by invitation)
Operative Results of Bone Cysts—Henry De Vincentis, M.D. (by invitation)
Osteoid Osteoma—R. R. Goldenberg, M.D.

The **U. S. Public Health Service Research Grants Program,** which has been in operation since 1946, is financed by public funds in the support of research, conducted without government control, by independent scientists. The purpose of these grants is to stimulate research in medical and allied fields by making funds available and by actively encouraging scientific investigation of specific problems on which scientists agree that urgently needed information is lacking. Since 1946, a total of $11,061,000 has been provided for the program, exclusive of appropriations for research grants in the fields of cancer and mental health. A total of sixteen grants, which represent an expenditure of $159,910, have been approved for research work in the field of surgery.

Late in 1945, the Research Grants Division was established to administer the grant program of the Public Health Service with Dr. C. J. Van Slyke as Chief. In July 1947, in order to effect coordination in the administration of the programs of research grants and research fellowships, the administration of the U. S. Public Health Service Fellowship Program was delegated to the Research Grants Division, which is now known as the Division of Research Grants and Fellowships.

Final recommendations to the Surgeon General of the Public Health Service are made by the National Advisory Health Council regarding all research grants, except those relating specifically to the fields of cancer and mental health, for which the National Advisory Cancer Council and the National Advisory Mental Health Council, respectively, are responsible.

At the request of the National Advisory Health Council, the fields of medical and allied research were classified into twenty major categories, and Special Study Sections, made up of consultant experts in these twenty fields, have been established. Late in 1946, the Surgery Study Section was organized with Dr. Frederick A. Coller, Professor of Surgery, University of Michigan School of Medicine, as Chairman.

Sixteen grants have been made for study in the field of surgery. Although most of the funds available for the fiscal year ending June 30, 1948, have been expended, the Public Health Service is encouraging investigators to present new applications in order to plan for next year's operation. Applications for new grants may be submitted at any time and should be addressed to: Chief, Division of Research Grants and Fellowships, National Institute of Health, Bethesda 14, Maryland.

Book Reviews

MEDICAL DISORDERS OF THE LOCOMOTOR SYSTEM INCLUDING THE RHEUMATIC DISEASES. Ernest Fletcher, M.A., M.D. (Cantab.), M.R.C.P. Edinburgh, E. and S. Livingstone, 45 shillings; Baltimore, The Williams and Wilkins Company, 1947. $11.00.

As the title implies, the object of this book is to bring together the available information on the medical disorders of an important system of the body, one which has tended to fall between the specialties of internal medicine and orthopaedic surgery. That this group of disorders should form an independent specialty, as advocated by the author, seems debatable; but further discussion on this point is beyond the province of this review. To accomplish this monumental task, Dr. Fletcher has been aided by the contributions of others well qualified to describe certain aspects of the subject. Among these, the chapter on "Applied Anatomy" by G. A. G. Mitchell stands out in clarity and conciseness, although the insertion of a larger number of illustrations and diagrams would be of aid to the reader. "Radiology" by F. C. Golding has been outlined only in respect to arthritis, but roentgenograms of other conditions have been adequately provided in the remainder of the book. W. S. C. Copeman has handled the subject of "Fibrositis" according to the prevailing British viewpoint, which is not accepted in entirety in this country. Other special contributions include "The Ear, Nose, and Throat" and "The Teeth as Sources of Focal Infection", "Medical Diseases of Bone", "Laboratory Findings in Rheumatism", and "The Incidence and Prevalence of Adult Rheumatism". The last, by a statistician, illustrates the inadequacy of available data, chiefly due to inherent difficulties in the diagnosis and classification of the rheumatic diseases.

The remainder of the book has been the responsibility of the author himself and is devoted to a systematic description of the wide variety of disorders affecting the locomotor system, with great emphasis and space necessarily given to the rheumatic disorders. In addition, there are separate chapters on the important and difficult subjects of "Sciatica", "Brachial Neuralgia", "The Shoulder Joint", and "Backache". The differential diagnosis of these conditions is presented in a helpful and informative fashion, as are, in general, methods of treatment. Topics omitted or inadequately treated for a work of this kind include lupus erythematosus disseminatus, dermatomyositis, scleroderma, amyloidosis, Dupuytren's contracture, and pigmented villonodular synovitis.

As stated in the Preface, this book is designed for the specialist in locomotor disorders. From this standpoint alone does the author seems justified in describing in detail a number of outmoded or unestablished methods of treatment, without definite statements of his opinion as to their value. The book can, therefore, be recommended unreservedly only to the critical reader with a wide experience in arthritis and allied conditions.

HOSPITAL CARE IN THE UNITED STATES. Commission on Hospital Care. New York, The Commonwealth Fund, 1947. $4.50.

The report of the Committee on the Cost of Medical Care in 1932 was the first comprehensive study of sickness, health, and hospitals in the United States. It considered the problem of sickness, and the extent and use of available treatment and preventive measures. It computed its cost to the patient and income to the doctor. The report presented the needs of the country in doctors and hospital beds, separating the cost of sickness into hospital costs, nursing costs, medicines, and professional fees. It clearly established the importance of hospitals in the medical structure.

Now, in 1947, this report of the Commission on Hospital Care further emphasizes the strategic position of the hospital by devoting its entire 600 pages to "A Study of the Function of the General Hospital, Its Role in the Care of All Types of Illness, and the Conduct of Activities Related to Patient Service, with Recommendations for its Extension and Integration for More Adequate Care of the American Public".

The Commission was composed of twenty-two persons, plus a study staff of nine, and eight technical advisers, assembled in 1944 by a Post-War Planning Committee appointed by the Trustees of the American Hospital Association. It was financed by The Commonwealth Fund, the W. K. Kellogg Foundation, and the National Foundation for Infantile Paralysis. Although its work antedated and was separate from the surveys authorized by the Hospital Survey and Construction Act, recently passed by Congress, its activities undoubtedly influenced the Congress and advanced surveys in the states. It is presented "to the American people as a guide to the future development of hospital care", and as such should commend itself to all serious students of medical and hospital problems.

One is somewhat overwhelmed by the 181 conclusions and recommendations presented in the second

chapter, until one realizes that herein are condensed in summary form the wide variety of subjects covered in detail in the next 300 pages.

Section III lays a foundation of facts and information dealing with a diversity of subjects, including factors that have influenced the growth of hospitals, such as religion and war; the growth of hospitals in the United States; the functions of a General Hospital; its relations with public health departments; standards of service; and financing.

The following sections, building upon this foundation, present new and original data under such titles as factors affecting the size and need of hospital facilities,—that is, population, vital indices, socio-economic conditions, geography, and transportation; the relation of bed-occupancy rate to size of hospital; the effect of urban or rural surroundings; and, finally, a formula for measuring the need of a community for hospital facilities by means of what they term the "bed-death ratio". This is evolved as follows:

It has been found that the public uses 250 days of general hospital care for each death occurring and correlated sickness cared for in a general hospital. Adjusting this on an annual basis (dividing 250 by 365 gives 0.685), we get 0.7 of a bed for each hospital death, or a bed-death ratio. This must be adjusted again to allow for a normal occupancy of 75 per cent., or 0.875 of a bed. The death rate in the nation is 10.6 per 1,000. The Commission assumed that one-half of these deaths might properly be expected to occur in hospitals, or 5.3. Consequently they computed 4.96 or 5 beds as the number of general hospital and allied special hospital beds per 1,000 population as the ultimate and ideal future need of the nation.

There are many methods of computing hospital-bed needs, but the Commission recommends this as the most reliable, pointing out that it is applicable under varying conditions of urban and rural areas, in low-income and high-income districts, and in other economic or population conditions; it expresses accurately the ratio of actual use, as well as the anticipated immediate needs, and can also be used to foretell future needs.

For example, when hospital deaths are 4.0 per 1,000, occupied beds are 2.8 per 1,000 population. As hospital deaths increase, so should the number of beds available be increased up to the assumed maximum of 5 beds per 1,000 population.

These 300 pages are the heart of the report and represent the constructive work of the Commission. The final 200 pages present the best history of hospital development in the United States yet compiled, and one to which reference will be gratefully made for years to come. This is interesting and instructive reading.

The final chapter presents a useful listing of all the governmental departments and agencies with which hospital administrators have to deal.

In short, this is primarily a reference book of great value for the planning of hospital development, illustrated with well-explained charts and tables, graphically showing the wide variation of hospital facilities and services in the different states. A practical yardstick for measuring hospital-bed needs, in the bed-death ratio, and future development and expansion for both urban and rural communities are discussed intelligently. Finally, there is an interesting and instructive history of hospital development in the United States.

RECONSTRUCTIVE AND REPARATIVE SURGERY. Hans May, M.D., F.A.C.S. Philadelphia, F. A. Davis Company, 1947. $15.00.

In this ambitious monograph, Dr. May has covered the field of reparative surgery in a very broad way. The general principles of reconstructive surgery, with special emphasis on plastic surgery, are well presented; and there is a splendid résumé of the newer thinking concerning wound healing and the treatment of burns, resulting from research during the last decade. In the chapters on surgery of regions, some procedures are discussed which are more commonly presented in orthopaedic writings or those of other surgical specialties. For example, several pages are devoted to acute arterial embolism and embolectomy; there is a lengthy discussion of reparative surgery of the large joints of the extremities, including the hip; and space is given to the operation of circumcision. The book suffers because this textbook approach to some of the multiple specialized problems of reconstructive surgery limits the possibilities of detailed presentation.

To the readers who refer to this book because of an interest in special phases of reparative surgery, careful study of the text and illustrations will be very enlightening. The author draws upon his early experiences with Lexer in Germany, and he quotes intelligently from the literature both of this country and of Germany. This book will thus be enlightening and valuable as a source for comparison of the techniques and methods in the two countries. Also, the reader will be repeatedly impressed with the contributions of the German surgeons of the last century and the early decades of this century.

To orthopaedic surgeons, the section on the extremities will be interesting. The author draws from the writings of others, but usually adds a comment based on his own experience. In the section of illustrative cases, a variety of methods of soft-tissue replacement of the extremities are demonstrated. The value of a familiarity with these methods is becoming increasingly apparent.

This monograph will be useful as a reference work on many phases of reconstructive surgery. The systematic and concise fashion in which the material is presented makes for easy reference. An extensive bibliography is included, which is well selected and general in its scope.

BONE AND BONES. FUNDAMENTALS OF BONE BIOLOGY. Joseph P. Weinmann, M.D., and Harry Sicher, M.D. St. Louis, The C. V. Mosby Company, 1947. $10.00.

This book was written by a pathologist and an anatomist, working at the School of Dentistry of the University of Illinois. They strive to remove "the peculiar existent dissociation of clinical, experimental, and pathologic endeavors on one side, and biologic thinking on the other".

Numerous working hypotheses were created by the authors to bridge the wide gaps in our knowledge of the pathology and physiology of the skeletal system. Many physicians and investigators will have a ready challenge for some of these hypotheses, and certainly many of the hypotheses will not stand the test of time. It is the authors' hope, however, that the reader will "look on the brighter side", and believe that even a false hypothesis has merit as a stimulus to future thought and research.

Part I deals with the normal structure and growth of bone and bones. Emphasis is placed upon the fact that bone is a tissue and that bones are organs. By this emphasis the authors clarify a widespread misunderstanding of one of the fundamentals of bone biology. Part I is a splendid review of our present knowledge of the histology and histogenesis of bone tissue and bones; in fact, this will be, to many readers, the most useful part of the book. The photomicrographs are particularly good.

Part II deals, in a limited manner, with the pathology of bone and bones. Numerous important entities are omitted and there is no discussion of the vast field of joint lesions. However, the authors make no claim to a comprehensive coverage of the subject of bone and joint pathology. As indicated by the title, the book is a presentation of fundamentals.

PICTORIAL HANDBOOK OF FRACTURE TREATMENT. Ed. 2. Edward L. Compere, M.D., F.A.C.S., and Sam W. Banks, M.D., F.A.C.S. Revised with the assistance of Clinton L. Compere, M.D., F.A.C.S. Chicago, The Year Book Publishers, Inc., 1947. $5.50.

A second edition of the *Pictorial Handbook of Fracture Treatment*, with revision of the text and additional illustrations, will be welcomed by all readers who wish to gain a comprehensive, although not a detailed, review of the basic principles underlying this immensely complicated subject. Few topics are so well adapted to pictorial analysis as that of fractures; and here, the authors have utilized their material admirably for setting forth what they call "the disciplines of fracture therapy". Where necessary, excellent photographic reproductions of roentgenograms have been introduced, but in the main, line drawings have been relied upon. These have been so well selected and prepared that they serve to illustrate the essential principles of the subject with outstanding clarity and simplicity. In this respect, they recall Cotton's fracture textbook, which excelled in this form of illustration.

From the title of this book, it might be suspected that the text would be subordinated to the illustrations. Fortunately, this is not the case. Without attempting to enter into discussions of disputed techniques, the authors have presented a concise description of universally accepted principles, omitting no major points. The text, like the illustrations, assumes a diagrammatic form, but it covers very satisfactorily all the more common conditions and procedures. Even a specialist, in reviewing this book, must concede that it summarizes the subject with a clarity that is often lost in more discursive texts, and yet without sacrificing any of the essential elements. In addition, the groundwork of corrective and reconstructive bone and joint surgery has been presented for the benefit of general practitioners who may not be familiar with the possibilities of more advanced treatment. Thus, cases requiring further care will be recognized and can be referred to specially qualified surgeons for whatever procedures may be required. All in all, this splendid condensation of the extensive and bewildering subject of fracture treatment into a convenient, compact, and clearly understandable handbook of 390 pages deserves unqualified approval.

FRACTURES RÉCENTES DU COL DU FÉMUR. INDICATIONS OPÉRATOIRES. ÉTUDE ANATOMIQUE. TRAITEMENT CHIRURGICAL (Recent Fractures of the Femoral Neck). Bernard Duhamel. Paris, J.-B. Baillière et Fils, 1947. 230 francs.

This book is based upon the study of 300 cases of fracture of the neck of the femur, treated at several hospitals in Paris. Statistically, the author shows that *true* cervical fractures occur more frequently in the very aged than is commonly believed. The major portion of this work is devoted to the true cervical fracture, and it is particularly in these cases that nailing is to be considered not as a method of improving function, but primarily as a means of saving life. Of a series of eighty patients operated upon between 1930 and 1940, nailing was done in 25 per cent. The total mortality, including the patients operated upon and those who were not operated upon, was 32 per cent. Of fifty-eight patients operated upon between 1940 and 1942, 46 per cent. had nailing; the total mortality (patients operated upon and not operated upon) had dropped to 28 per cent. In 1943, of forty-nine cases treated, 74 per cent. were operated upon, with a total mortality of 17 per cent. In 1944, of 22 patients, nailing was performed in all, with a mortality of 16 per cent.

The author devotes most of the remainder of his monograph to a consideration of the following factors:

1. The anatomical structure of the neck of the femur;

2. The mechanics of fracture of the neck;
3. A classification of the various types of fracture.

In his discussion of the mechanics of the femoral head, much is lost by the use of diagrams which are inadequately described. In the chapter dealing with definite treatment, the author deprecates the use of general or spinal anaesthesia. By preference, he operates after the subcutaneous injection of two cubic centimeters of "nargenol", followed by the intravenous injection of ten milligrams of pure morphine. The importance of accurate reduction is stressed, and the Leadbetter method is discarded as inadequate. The importance of lateral traction to disengage the fragments, followed by internal rotation, is emphasized.

The Whitman manoeuvre of abduction is not a method of reduction, but a means of maintaining a reduction which has already been achieved. In nailing, this manipulation is unnecessary, and the only objective is perfect reduction.

If this can be achieved, a nail of adequate length must be inserted. Since the roentgenogram cannot assuredly be exposed in a plane parallel to the axis of the neck, roentgenographic measurements will be inaccurate; and the only true gauge of the length of the nail is the length of the guide wire which should be inserted. In order to direct the nail properly, the author has devised a rectangular, parallel-edged, double guide. It would appear to the reviewer, who lacks any actual experience with its use, to be more cumbersome than the guides which are familiar to American surgeons.

Although the points of view expressed by the author of this short monograph are not new, the presentation is so eminently logical and well organized that its reading is well worth while.

CINEPLASTY. Henry H. Kessler, M.D., Ph.D. Springfield, Illinois, Charles C. Thomas, 1947. $6.75.

The over-all management of the upper-extremity amputee from the time of amputation to his rehabilitation and return to work is one of the most important problems the orthopaedic surgeon has to face. The author has realized this for many years, and his interest and experience in this field have eminently qualified him to write an authoritative treatise such as this, covering the whole field of upper-extremity amputations. That is what it is,—it is more than a treatise on cineplasty alone.

The first three chapters are devoted to general considerations, functions of the upper extremity, and mechanical prostheses. In these chapters the fundamental philosophy and understanding of arm amputations in general are adequately discussed. Cineplasty is traced in the next five chapters through its history, physiology and anatomy, surgical technique, aftercare, and prosthesis. Other interesting chapters follow, on congenital amputations, double amputations, and plastic procedures. The final chapter on rehabilitation of the arm amputee covers the important points in this field. The book is well illustrated.

The author has presented an excellent coverage of the standard Sauerbruch method of cineplasty and cineplastic prostheses for the upper extremity, essentially as it was practised here and abroad up to and including World War II. Unfortunately, some recent knowledge concerning cineplasty and its prosthesis was not available before publication of this book. The highly important work done by the Committee on Artificial Limbs of the National Research Council will supplement Dr. Kessler's work, and should be known to all who have responsibility for rehabilitation of the arm amputee.

Further understanding of fundamental muscle physiology with regard to the requirements of the cineplastic prosthesis and the development of a new and better prosthesis, now the subject of research projects of the Committee on Artificial Limbs, should be of practical value in the further use of this method. Some further refinements of the surgical principles and technique already developed will also enlarge the field of usefulness of cineplasty.

EL ENCLAVAMIENTO INTRAMEDULAR DE KÜNTSCHER. C. Gil Turner. Madrid, *Revista Española de Cirugía*, 1946.

Turner reports his experience with the intramedullary nailing of fractures at the Hospital Provincial in Madrid. This method provides perfect reduction and complete immobilization of the fragments. No rusting of the stainless-steel nail was seen. In one case the nail bent in two weeks. Each long bone presents mechanical problems because of the size and shape of the medullary cavity. The part that the medulla plays in the healing of fractures is small. The V shape of the nail produces a minimal amount of injury to the medulla, and histologically no pathological lesions are found. Changes in the blood picture after nailing are sometimes seen in children; there may be slight eosinophilia. No other changes were seen. No change in the regeneration of the bone appears to result from the presence of the nail.

The indications for nailing are: (1) in cases of fracture in which the general condition is poor and the patient should not remain in bed; (2) in non-malignant spontaneous fractures; (3) in transverse diaphyseal fractures which tend to become dislocated laterally; (4) in fractures which are reduced easily, but in which bowing cannot be prevented; (5) in fractures with a third triangular fragment; (6) in fractures with dislocation of the humeral neck; (7) in pseudarthrosis, cases of delayed union, and in corrective osteotomies; (8) in recent compound fractures.

No cases of infection were observed. Seven cases are reported in detail, and no bad results have been observed.

When used in the conditions for which it is indicated, the author feels that this is a very important addition to the treatment of fractures. This method should not be used generally, since in most cases satisfactory results will be obtained by the older methods. The older methods of osteosynthesis, however, are more dangerous than this procedure.

HISTORY OF MEDICINE. Cecilia C. Mettler, A.B., Ed.B., A.M., Ph.D. Edited by Fred A. Mettler, A.M., M.D., Ph.D. Philadelphia, The Blakiston Company, 1947. $8.50.

This monumental volume of over 1,100 pages inevitably invites comparison with such other well-known monographs in medical history as those by Castiglioni, Cordell, Cumston, Dunglison, Garrison, Packard, Robinson, Sarton, Sigerist, and Singer; yet it differs from them all in approach and purpose. More nearly it is akin to Gordon's recently published "Romance of Medicine". Its composition occupied the last nine years of the author's life, and it was completed only a few days before her sudden and untimely death on November 27, 1943. The research necessary for its production was made possible by the Benjamin Salzer Fund. It has now been edited and prepared for publication by Dr. Fred A. Mettler, Associate Professor of Anatomy at Columbia University. It has copious indices of personal names and of subjects, and is illustrated by sixteen well-chosen portrait engravings, one at the beginning of each chapter.

This work aims to be "a correlative text arranged according to subjects"—anatomy, physiology, pharmacology, pathology, physical diagnosis, medicine, neurology, psychiatry, venereology, dermatology, pediatrics, surgery, obstetrics, gynecology, ophthalmology, otology, and rhinolaryngology—each chapter being followed by a series of selected readings, totaling several thousand references. Neurosurgery, orthopaedics, and urology are included in the chapters on pathology, neurology, pediatrics, and surgery. It seems unfortunate that these distinguished, important, and prominent specialties, which have extensive roots and sources in history, are not accorded separate consideration. The essential purpose of the work, however—namely, to demonstrate and establish the continuity of the present with the past, which constitutes true conservatism—is abundantly well fulfilled. It is a contribution of notable and outstanding value to humanistic scholarship in medicine.

SURGERY OF THE AMBULATORY PATIENT. Ed. 2. L. Kraeer Ferguson, A.B., M.D., F.A.C.S. With a section by Louis Kaplan, A.B., M.D., F.A.C.S. Philadelphia, J. B. Lippincott Company, 1947. $10.00.

This large volume of 932 pages deals, as the author says, with ". . . a subject much neglected in modern medicine". The desirable features of performing operations and procedures in the office, as opposed to a hospital, are pointed out. The author cautions against attempting an operation when "the diagnosis is in doubt or the extent of the lesion not definitely known", and concludes his introductory chapter with the statement: "Ambulatory surgery should be safe surgery". With this statement all should be in agreement.

The first part of the book deals with "Surgical Principles and Lesions". Equipment, anaesthesia, dressings, et cetera are discussed, and then various types of injuries and lesions are described, together with their treatment.

Part II is devoted to "Regional Surgery". The author takes up each anatomical section of the body and describes the lesion to be encountered there. One is somewhat startled at some of the lesions which the author advocates operating upon in the office: mixed tumors of the parotid, excision of thyroglossal cysts, tumors of the breast, excision and primary closure of pilonidal cysts, fistula in ano, division of the scalenus anterior, drainage of acute suppurative tenosynovitis, excision of Dupuytren's contracture, et cetera.

Part III deals essentially with fractures and dislocations. This is a clear and complete exposition of the non-operative treatment.

The volume is an encyclopedia of the diagnosis and treatment of the less severe surgical conditions. The chief criticism should be leveled at the emphasis placed upon what operations *can* be performed in the office rather than on what *should* be. If the book does not excite the inexperienced practitioner to attempt more than he is able to accomplish, it will prove of great value.

PHYSICAL MEDICINE IN GENERAL PRACTICE. Ed. 2. William Bierman, M.D. With a chapter by Sidney Licht, M.D. New York, Paul B. Hoeber, Inc., 1947. $8.00.

This can, in general, be recommended as an adequate textbook of physical medicine. Details of technique, particularly in the field of electrotherapy, are covered sufficiently for the physiotherapist and specialist in physical medicine. In the attempt to describe practically all procedures which might be used, there results for the general practitioner possible confusion as to optimum methods. The author frequently refers to the literature and leaves the reader without information concerning the usefulness of the measures,—for example, diathermy for chronic inflammation of the liver, gall bladder, and for peptic ulcer.

The fine line drawings add immeasurably to the value of the book, particularly in relation to performance of exercises. In this second edition the most significant alteration is the inclusion of a chapter by Sidney Licht, M.D., on medical rehabilitation, which is now recognized as an important part of physical medicine. In future editions, it would be well to amplify this section of the book still further. Other deficiencies which might be pointed out in view of future revisions are inadequate description of electrodiagnostic methods, including determination of strength-duration curves, tetanus ratios, electromyography, and the use of other recently available electronic equipment. Progressive-resistance exercises appear to have enough widespread acceptance to be included in the textbook. The section on rheumatoid arthritis seems too brief, considering the importance of physiotherapy in the treatment of this disease. The same also applies to infantile cerebral palsy. The specialist in physical medicine would also like to have amplification of diagnostic procedures in this field, including techniques of mensuration of strength, joint range, manual skill, fitness, and circulatory function.

This field is expanding so rapidly that it is hoped that revisions of this excellent text will be frequent.

LA EQUINOCOCOSIS OSEA (Osseous Echinococcus Infestation). Hebert Cagnoli. Montevideo, Casa Impresora "La Industrial", 1947.

In this monograph Dr. Cagnoli, of the Traumatological Institute in Montevideo, reviews the literature and reports his personal experience in the treatment of echinococcus cysts of the bone. The embryos are carried from the intestinal tract to the bone by way of the blood stream. Bone infestation is rare, because the portal and the pulmonary slowing of the blood stream sift out most of the embryos. One rarely finds hydatid cysts elsewhere, when they are present in the bone. The bones most frequently affected are the vertebrae (40 to 50 per cent.), the femoral head, the humerus, the tibia, and the femur. At first the cyst is unilocular. The changes which it produces in the bone are the result of two factors, mechanical and toxic. There is no reaction on the part of the affected bone, and the osseous morphology is usually maintained. Two distinct syndromes appear, depending upon the localization of the cyst, the diaphyseal syndrome which often results in spontaneous fractures, and the epiphyseal syndrome which often produces articular symptoms. If the cyst is adjacent to bone or breaks through the bone, it may form a pseudo-abscess or multiple or solitary hydatid cysts.

The complications which arise are fracture, secondary fistulization, and invasion of the adjacent soft parts. The evolution of the lesion is very slow, but steadily progressive. Symptoms often appear late, since there are no inflammatory phenomena. There may be pain, a tumor, a fracture, muscle spasm, or fluid in a joint. There is no general reaction; the parasite is symbiotic with its host.

In the diagnosis, the roentgenogram is of most value. Biological tests, such as the reaction of Casoni and the complement deviation, are of insufficient accuracy to confirm the diagnosis. Eosinophilia of considerable degree is usually present. The roentgenogram shows an invasive lesion, with no bone reaction. There are small confluent zones of areolar osteolysis, limited by dense trabeculae. The prognosis depends upon the location, progression, and degree of evolution of the lesion. Treatment, to be effective, must be early, and consists of radical surgery. Local resection may be done if the condition is seen very early. Complete resection of a bone may be required. In the vertebrae, in which treatment must be limited to curettage, a cure frequently is not effected. Where surgery cannot be carried out, biological treatment should be tried, using the echinococcus embryo after the technique of Caleagno. Little can be expected from such treatment, however. The mortality from this disease is always 50 per cent. or higher. In cases with spinal and pelvic localization, the prognosis is particularly grave.

THE AMERICAN ILLUSTRATED MEDICAL DICTIONARY. Ed. 21. W. A. Newman Dorland, A.M., M.D., F.A.C.S. With the collaboration of E. C. L. Miller, M.D. Philadelphia, W. B. Saunders Company, 1947. $8.50.

The revision of a medical dictionary is never an easy task; at the present time it must be an especially formidable undertaking. During the years since the last edition of this authoritative work was published, there have been many additions to medical terminology, resulting from the research of the war years and the countless new discoveries of this period. The compilation of a comprehensive dictionary must not only include the new terms which have crept into a well-rounded medical vocabulary, with their accurate definitions, but must also eliminate the obsolete and those no longer considered in good usage.

Those who are accustomed to depend upon this dictionary will be grateful for the new edition. It includes a number of new colored plates, some of which are excellent. Two deserving of special mention are the plate of the anterior pituitary hormones and that of the life cycle and comparative morphology of the malarial parasites of man.

The publishers may well be proud of this latest addition to their long series of medical dictionaries and related publications.